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Editorial: Importance of pedagogy

Kay Stables, Goldsmiths, University of London, United Kingdom

A significant thread runs through the articles in this issue of the journal – a focus on pedagogy. As a collection, insights are provided into pedagogy in informal, maker space settings with young children, undergraduate engineering courses, undergraduate design courses and postgraduate courses, including one where the focus is on design for health. The pedagogies presented vary from those that are loosely structured to those that are highly structured. Some involve working with professional contexts, some are explored across disciplines. One thing that the articles have in common is putting the learner at the centre. A range of approaches to doing this are portrayed, providing excellent detail and examples to be shared. A common feature is the tricky and challenging management of a shift from transmissive to transformational educational experiences. Through this issue's collection, there are lessons to be learned and ideas that can be unpicked that can transcend both age and educational level boundaries.

The importance of placing the learner and learning at the heart of pedagogic practices is highlighted at the outset through this issue's Reflection piece by Richard Kimbell, (Goldsmiths, University of London, UK). In *Transformations* he explores this through the lens of the 'butterfly' effect – how a small change in one place can have the ability to create massive and unexpected change somewhere else and, in an educational context, especially when pedagogy is at the core.

In the first research article - *A study of children's relationship with making and use of CAD in collaborative, informal environments and the implications for institutional learning environments,* Denise Allan, Samantha Vettese and Paul Thompson (Edinburgh Napier University, UK) report on a study undertaken in an informal education setting with children who attend a 3D printing club. The research focuses on how children engage with digital making processes in an unstructured environment. Drawing on literature on learning in the context of digital making, online communities, builder gaming and digital technologies, the researchers developed research analysis underpinned by constructivist learning. Through this they explored how an informal club setting can affect outcomes of children's learning, designing and making experiences, how children's online hobby led activities compare with learning outcomes in the club setting and to consider how the results may relate to institutional environments. The article reports on a study that involved over 100 children, focusing in detail on two contrasting case studies, one of a six year old and the other of a ten year old. Both children were using the same modelling software and their behaviour illustrates insights identified across the larger group, including differences in approaches to open ended exploratory play and problem solving and more goal focused approaches and how being part of online maker communities impacted on aspects such as perseverance. The authors conclude the article with comments on positive approaches that could be transferred to institutional setting that can help acquisition of a range of skills such as team work, research, communication, designing thinking, innovation and cooperative learning.

In *Learning Engineering through the Flipped Classroom Approach - Students' Perspectives,* Wendy Fox Turnbull (University of Waikato, New Zealand), Paul Docherty and Pinelopi Zaka, (University of Canterbury, New Zealand), begin by providing a brief background on, and incentives for exploring, a flipped classroom approach. Interestingly there are some parallels here with the previous article by Allan, Vettese and Thompson, drawing on similar learning theorists and a focus on learner-centred pedagogy, the value of learning communities and teacher as facilitator. The research explored flipped learning within a condensed summer school setting, two years in succession, with first year engineering undergraduate students. The methodology used was interpretivist, using interviews to gather perspectives from students involved. Student comments were divided between aspects relating to how students' learning behaviours and teachers' teaching behaviours differed from more traditional approaches. Within this, students highlighted aspects such as gaining a deeper understanding of materials as a result of advance reading, followed by peer discussion, for example how collaboration involved discussing differing opinions that helped advance knowledge and understanding. They also highlighted the additional time they needed to invest in the course but the ability to adjust course content delivery rate. Interestingly the students also considered that they needed to have a pedagogic understanding of the approach. Summary recommendations for lecturers included having varied and quality materials, signalling workshop materials in advance and preparing students for the pedagogic approach of flipped learning. Recommendations for students included having a positive attitude, thorough preparation, being organised, managing time and understanding the value of collaborative learning. The research reported here focused on engineering students. The next stage is to explore further with design and technology students in secondary and tertiary settings. Watch this space.

In *Exploring the relation between students' research behaviours in project courses and open innovation*, Ilgim Eroğlu (Mimar Sinan Fine Arts University, Turkey) and Deniz Ekmekçioğlu (Ondokuz Mayıs University, Turkey), explore the concept of open innovation more generally, and then focus specifically on how this is used and understood by undergraduate product design students. The authors highlight two areas of study of open innovation – that focusing directly on designers and that which focuses on management and linked use of design thinking. They suggest that for design students, both design and management opportunities provide good reason to highlight open innovation. A detailed background is provided to scope out what previous studies have already provided insights into, and the strong relationship between open innovation and processes of designing. They then report on research undertaken with senior design students to understand their awareness of open innovation. Data was collected from undergraduate students across five universities in Turkey. Students responded either by interview or in writing to questions focused on Likert style and open responses. The questions had three focuses: first how students conducted research; second how, and if, they shared information; and third their general awareness of research processes and open innovation. Findings indicate that students' explicit knowledge of open innovation processes is slight, but their research actions do align with open innovation processes. However, the authors consider that the lack of explicit understanding of the concept may prevent them fully understanding the value of sharing information and hamper them in future professional settings.

In *Design Divergence Using the Morphological Chart*, Naz Börekçi (Middle East Technical University, Turkey) focuses research on the potential of morphological charts to support idea generation when designing for complex functions. The article begins by providing a background on morphological chart method and its value in providing analytic support to creating both design divergence and convergence. The author then introduces research undertaken with graduate students from a range of design and other backgrounds that explored the factors that affected performance and strategies employed when using a morphological chart based on a short-term design project on drip filter coffee machines. The article provides a detailed outline of the pedagogic structure of the project presented to the students. This includes trialling existing products, determining sequences of operation, identifying product components and sub-functions, how components interact, undertaking a morphological analysis, preparing a morphological chart and then undertaking re-design. Detailed analysis of the impact of each pedagogic aspect provides valuable insight into the approach and how the structure allowed students to take a more holistic approach to their designing. A set of conclusions provide clear insight into how the approach supported students in manifesting design divergence. Despite being undertaken with graduate students, insights provided in this article could usefully be drawn on by those supporting design projects at any level of education.

In Problem based learning: developing competency in knowledge integration in health design, Katherine Sullen (OCAD University, Canada) provides insight into how students deal with the challenges of different stakeholders and multiple 'truth' regimes when designing. The specific context of the article is that of design for health and the reported research is undertaken with graduate (M.Des) students. The students were engaged in re-designing a re-habiltation centre within a geriatric psychology unit. The article presents an overview of the structure of problem based learning within the M.Des curriculum in question and how they are introduced to the concept and various categories of potentially conflicting truth regimes of "Scientific", "Mundane", "Symbolic" and "Governmental" truths. The author shows how these 'truths' help structure a framework that can be used by students to work across truth regimes to seek out new knowledge, to encourage reflection on diversity of perspectives and to support integrating knowledge across regimes. It also supports students to consider the position and responsibilities of the designer within and across these regimes and how design's 'truth' can be made visible beyond the world of design. Sellen concludes by highlighting the challenges of implementing a model that engages with knowledge that extends far beyond what might be considered design knowledge. However, she also highlights the potential for hybrid approaches to design and integrating across truth regimes.

In *Design for Manufacture (DFM) within Professional Practice and its Relationship to Design Education*, Tom Page (Nottingham Trent University, UK) explores how Design For Manufacture (DFM) is taught in higher education and compares this with the requirements of professional practice. The benefits of DFM are highlighted through a review of literature, but the author reports that it is less clear if an understanding of these benefits is explored in tertiary design education. The latter formed the focus of research for this article. The research data was gathered by two sets of questionnaires: the first undertaken by current and graduate Industrial Design and Product Design students, the second with companies that had either employed or offered placements to former students from the same university courses. Student data was collected on their experience of industry (e.g. via a placement), what they saw as the most relevant skills for professional practice and how their university courses could be improved in the context of preparing for professional practice (and in particular DFM). Companies were asked to prioritise the four most important skills in graduates and also to identify which skills needed most development when graduates entered the workplace. They were also asked at which stage the company considered DFM and whether students had enough understanding of its role. The research revealed that both students and companies placed Computer Aided Design and DFM as the most important skills needed, highlighting the importance of DFM. However, the companies considered that the university students had inadequate understanding, while the students highlighted a need for more focus on teaching DFM at university. While the focus of the research was on one specific university, the industry view was that this university prepared students as well, if not better than other universities. A thread running through the article is the changing role of designers. The shift caused by the development of new technologies was seen as significant in this. The article makes a claim for the contribution of Industrial and Product Designers in managing this shift and for a consequent need for greater emphasis on DFM within design education.

The final two articles in this edition of the journal are from Mauricio Novoa (Western Sydney University, Australia), both reporting on research that has focused on major development in design education curriculum at the tertiary level.

In *Innovating Industrial Design Curriculum in a Knowledge-Based, Participatory and Digital Era*, Novoa provides the story of three years of research that led to an innovative undergraduate industrial design curriculum that created a shift from a transmissive teacher-centred model to a transformational learner-centred model that draws on a human centred approach, critical design and making, design heuristics, Conceiving, Designing, Implementing and Operating (CDIO) and Science Technology Arts and Mathematics (STEAM). An aim was to provide a foundation for education towards a 4.0 industrial revolution, enabling a focus aspects such as human computer interaction, machine learning, hacker cultures and open-source developments. The development was explored by reviewing existing structures and recent developments using epistemology, Cultural and Historical Activity Theory (CHAT) and curriculum lenses that provided the impetus for writing a vision and mission that led the re-positioning and development of a new curriculum.

In a companion article, *Industrial Design Education as Innovation Broker through Making, Pivot Thinking, Autopoiesis and Expansive Learning*, Novoa reports on research undertaken in the context of a final capstone project with industrial design students. The focus is on the behaviour, cognitive and social learning of the students though four specific processes: critical making, pivot thinking, autopoiesis and expansive learning when they became active junior designers in a design agency environment. The article introduces the four processes and then provides a detailed account of the research and pedagogic development that took place over eight years of iterative trialling, reflection and further development supported by Participant Action Research (PAR) and Developmental Work Research (DWR). The story told through the article is one that exemplifies how a visionary model can employ an active, evolutionary approach to meticulously and painstakingly create a curriculum model that makes a major shift from a transmissional to transformational approach, where the outcomes equate both to the achievements of the students involved and pedagogical messages that can be passed to other educators. The latter include what are identified at the end of the article as 'tipping points' - post-mortem recommendations made by students experiencing the programme. The article provides both a model and an inspiration to anyone with aspirations to make major changes in an educational setting.

Finally, this issue of the journal concludes with a review by Danah Abdulla (Brunel University, UK) of a new book *by Alice Rawsthorn - Design as an Attitude*. The book presents a set of chapters drawn together from a series of articles on the topic of design as attitude, written by Rawsthorn for Frieze magazine. The review provides a critique that highlights the value of the book but that also, reflecting from the perspective of 2018, takes issue with matters that are absent from the book's agenda.

Transformations

Richard Kimbell, Goldsmiths, University of London, UK

I have always been aware of the butterfly effect. It is a theoretical phenomenon that argues that a butterfly flapping its wings in one place can cause catastrophic effects somewhere else. Whilst this example sounds a bit far-fetched, I do keep coming across less extreme but very interesting examples of it.

An example arose in a great book I am currently reading; "The Last Wolf" by Robert Winder about England in the 13th century. In 1281, Edward 1 ("long-shanks") required one of his knights, Peter Corbet, to rid England of wolves. They had in any event been in decline for decades. Magna Carta (1215) reports a reward of 5 shillings for a pelt, surely too big a sum to be easily earned, but lambs and travellers through dense forests were still threatened by packs of wolves, and frightening stories of tooth and claw featured large in early medieval consciousness. But by 1290, Corbet - with his hunting parties and dogs - had seen off the last of the wolves and was rewarded with a seat in Edward 1st parliament. The English county-side had been tamed.

It was not intended that this single action by an obscure Shropshire noble should transform the economy of England – but it did. Over the channel in France, Holland, Switzerland, Germany and Italy (and of course the whole of Scandinavia) the wolf-packs remained unchallenged. They could move in and out of the vast Russian (now east European) forests in numbers far too great to control, and right across Europe, shepherds were forced to bring their flocks into protective pens every night. Sheep farming on the continent was a hazardous business. But after Corbet, Winder describes how … "in England, an Anglo-Saxon – Viking – Celtic witch's brew of an island governed by Norman occupiers would turn into the biggest sheep farm in the world, and become the source of its finest wool."

The vast wealth created by the wool trade across to the continent is evident in the wonderful buildings in Essex and Suffolk on the route to the East Anglian channel ports, not least Dunwich which has long since been lost to coastal-erosion. But perhaps the biggest indicator of the significance of the wool trade is in the 'wool-sack'. In the 14th C Edward 111 commanded that his Lord Chancellor – whilst in Council – should sit on a wool bale to symbolise the huge importance of wool to the English economy in the Middle Ages. The woolsack remains central to parliamentary procedures to the present day.

What struck me as interesting about this wolf story was that so much had been transformed; our farming, our economy, our trade and even our parliamentary procedures, and yet it was (to me) a completely unknown incident. It seemed like a 'butterfly' story, with Corbet fluttering his wings in the forests of England in the 13th century and causing England to be completely re-made for the next seven centuries. And there is of course a connection between this butterfly example and the tricky business of teaching Design & Technology (D&T).

When I started teaching in 1970 I was surrounded by schools – and teaching practices – that were dominated by craft traditions in wood, metal, textiles and food. But fortunately this was a time in which experimentation was not only allowed it was deliberately encouraged – not least within the 16+ assessment processes. We were allowed to create our own courses and devise our own examinations. So I did. But a few years later I was faced with the challenge of encouraging other teachers (and student teachers) to build design thinking into their courses and thereby into their learners' experiences. On the face of it, this appeared to require a huge transformation of thinking from predetermined craft practice to learner-initiated design decision-making. Surely too big a step to be easily taken. So I experimented with ways to make the transition easier. And the more I experimented, the more I realised that the difference between them depended on where you were looking.

We might imagine a project comprising tangible and intangible elements. The tangible (observable) elements involve the materials and the tool processes that result in a product. They can all be seen, smelled and touched. The intangible elements are far more difficult to see. They exist as intentions in the mind of the teacher and as intellectual processes embedded in those material, tangible, bits and pieces.

Imagine a project. Learners are using a construction kit (like LEGO) to create a small, independently powered buggy with a steering system and a built-in light sensor. The idea is that - when switched on and let loose – it will trundle around the room and when it hits an obstruction (a chair leg) it reverses and turns away from the light. Its behaviour appears to be such that it is 'hunting' for darkness and it ends up in the deepest darkest corner of the floor. The tangible features of the project - the LEGO blocks and switches and sensors – might suggest that this is an appropriate D&T project. But to be sure, we need to know more than that which is observable in the product (the buggy). We need to get inside the head of the teacher and grapple with his/her intangible intentions. The buggy might be a challenging, design-rich experience for learners. Or it might just be a bit of vaguely interesting rule-following (LEGO-plan following).

But teachers' intentions *are* of course observable – not in the *objects* under construction but in the less tangible features of the learning exchange. They emerge through the questions that teachers ask; through the challenges they throw at learners; through the way the room and the working groups are set up; through the way that the modelling kit is presented; through the guidance about 'what counts' as success; and through the myriad other considerations that make up an appropriate pedagogy for D&T. The bottom line is that D&T is not defined by the tangible stuff that typically makes up its content. It is ALL about the intangible intentions that teachers enshrine in their method of teaching; their pedagogy.

In fact the tangible elements can sometimes be seriously misleading. On the face of it a room full of youngsters making mechanical buggies screams out 'Design & Technology!'. But it might not be. Conversely a room full of youngsters sitting and discussing something does not immediately shout 'Design & Technology!' But it might be.

So, if the buggy might be – or might not be – good D&T, and if the difference between them lies not in the materials, components and tools in the teaching room but rather in the teacher's intentions and practice, then – I argued to myself – surely it's a small matter to help all teachers to become great D&T teachers. How naïve. It is true, I think, that the tangible differences between good D&T and not D&T are small. The buggy, the chair, the identity bracelet might all be either. But good design teaching involves a sophisticated pedagogy, and helping teachers to get to grips with it is a very challenging task, not least because of the uncertainties that inevitably arise as learners make their own design decisions.

Oddly this reverses my 'butterfly' notion. For it argues that small differences in the tangible/observable outcomes of projects result from the most profound changes in teachers' practice. So why would we bother? If the material outcomes end up looking more-or-less similar, why go through all that sophisticated practice to get there? Because, of course, its not the buggy or the bracelet that matters. It is the *learner* and how their design-struggle transforms them into creative and independent thinkers.

I was recently in a school where the conformist (Gove-ist) pressure on the curriculum has resulted in Design & Technology being 'merged' with science. And I note that the new curriculum in Wales specifies a Science and Technology Learning Area. In these tricky times it is more important than ever that teachers have a good grip on what makes Design & Technology what it is. The observable material content of projects is (I have argued) not critical and is completely negotiable. But the underlying purpose – and its associated pedagogy - is absolutely vital.

So how might we summarise those non-negotiable principles that define D&T and that represent our covenant to learners. By learning to think and act creatively and independently we can build a better world. Not following others' plans but working out for ourselves what improvements are worth making; how we might bring them about; and having the capability to enact them.

We realise these ambitious goals in the material world because the consequences of our decision-making are always so evident there. In a D&T learning environment, our ideas cannot hide or be fudged. Our thinking is squeezed between our design vision and the ruthless reality of the material world, which is an unforgiving and powerful teacher. But if the material world – the made world - provides a wonderful Montessori experience in which learners progressively acquire the capability of creative and independent thought, that is not the end of the matter. For a creative and independent thinker will not be told that they can only exercise their capability in that material world. They will – quite rightly – want to spread their wings and tackle tasks that go way beyond the concerns of the made world… into social policy, archaeology, economics, history, law and philosophy.

In short, the aim of a great Design & Technology programme is that learners will grow to be educated in the fullest and richest sense …enlightened, discerning, discriminating, and capable.

And a Design & Technology learner flapping her wings just might change the world.

A study of children's relationship with making and use of CAD in collaborative, informal environments and the implications for institutional learning environments

Ms Denise Allan, Edinburgh Napier University

Dr Samantha Vettese, Edinburgh Napier University

Dr Paul Thompson, Edinburgh Napier University

Abstract

In this article, the researchers investigate different ways in which school age, 'generation net' children learn, through non-linear, mediated, collaborative 'making' environments, enabled by informal club settings and online 'builder' gaming and groups. In addition to this, the study will investigate these learning methods in relation to children's future attitudes to formal education and their engagement with the ethos of open access digital fabrication facilities.

The research will draw upon primary sources including the observation and analysis of children who attend 3D printing clubs created by one of the authors. These clubs are aimed at children who are just starting their formal school education, from the age of six. The clubs are informal and relaxed to allow a great deal of creative freedom. The children have access to 3D printers, CAD software and 3D printing pens to allow them to explore the technology and design process in different ways. They can choose to work together or alone, and can participate in the group discussion in an unforced way. This research will conclude by analysing the educational benefits of informal shared design practices and digital fabrication making processes and how they could be used in the learning spaces of the future.

Key words

making, builder games, 3D printing, computer aided design, informal spaces, learning

Introduction

This research examines several characteristics of the digital making process. In particular, it will look at ways in which children engage and learn when given the access to these informal maker environments and tools. It will then consider how their particular ways of interacting with these approaches and processes may influence current and future learning strategies, which could be applied to more formal and institutional environments.

Children, making, and what we can learn from their methods and creations, in an 'unstructured' environment is well documented, although not always put into practice in institutionalised places of learning. The idea that education should be more experiential and connected to real world objects is originally attributed to John Dewey but also to many other scholars and innovators including Froebel, Freudenthal and Montessori. (Dewey, 1902; Freudenthal, 1973; Froebel, 1887; Montessori, 1964). Freire, (1973) introduced the idea of culturally meaningful curriculum construction, in which designers get inspiration from the local culture toward creating 'generative themes' with members of these cultures. Papert’s (1980) theory of constructionism describes the importance of learning through the experience of doing.

This research, based on a case study from a digital making club set up by one of the authors, called ‘Wee Replicators’, observed how children naturally interact with digital technologies and how these children are informed by their experience of digital ‘builder games’ such as Minecraft. This research explores the relationship between digital experience of CAD (Computer Aided Design), through online interaction in shared space games, and physical CAD, through 3D printing technologies at a children’s maker club. The children observed in this study showed a flexibility in their use of CAD and 3D printing technologies, with innovative results that might not have been achieved through a structured taught programme. Their designs and objects created were reflective of and directly inspired by their 'hobbies'. These results were then analysed alongside the existing literature on making and constructivist learning. Through this theoretical and empirical study, implications for educators and learning spaces of the future will be proposed, contributing to long standing debates around progressive versus institutionalised learning. The main aims of this study are therefore:

- To investigate how informal club settings and the devices used within them affect the outcomes of the children’s’ learning, designing and making experience
- To compare the children’s’ experience of online, hobby led activities with their learning outcomes in the digital making club setting
- To synthesise these results into outcomes that may relate to institutional environ-ments for multi-generational learners

Literature Review

Digital Making, 'Connecting' [Processes and People] and Learning

There are many definitions of ‘connecting’. In this study, it is considered in the context of how children connect with other individuals in an informal group setting, including with their ‘mentor’ and peers; as well as how children connect the multifaceted processes involved in making through different physical activities and different combinations of all these interactions. The value of this type of connecting may not always be appreciated as a way of learning in institutional environments.

According to Gauntlett, (2011, p.2)

> “[digital] making is connecting because you have to connect things together (materials, ideas or both) to make something new; making is connecting because acts of creativity usually involve, at some point, a social dimension and connects us with other people and making is connecting because through making things and sharing them in the world, we increase our engagement and connection with our social and physical environments.”

These processes were all embedded, informally, into the Wee Replicator digital making clubs.

Research around making and connecting also explores the connected interaction between a sense of self, emotional expression and tangible physical outcomes. Margetts (2011) believes that

> “making is a revelation of the human impulse to explore and express forms of knowledge and a range of emotions; an impulse towards knowing and feeling, which shapes human action and hence the world we create. The reward of making is the opportunity to experience an individual sense of freedom and control in the world. Making is therefore not only a fulfilment of needs, but of desires – a process whereby mind, body and imagination are integrated in the practice of thought through action.” (Margetts, 2011, p.39)

Looking at children in particular and the way they connect in online games, sharing their processes and ‘creations’ and learning is also of relevance. Gershenfeld (2005) said that,

> “the inventiveness of children has led to a historical blurring of the distinction between toys and tools for invention, culminating in the integration of play and work in the technology for personal fabrication.” (Gershenfeld, 2005, p.133)

This highlights the potential of integrated learning through play for productivity and comprehension. Fox (2014, p.20) said, “in workshop based third wave DIY, manual manufacturing can facilitate social learning.” By working with or in the company of others a sense of camaraderie may develop which can lead to empathy and a more meaningful shared experience. This type of learning, which encourages empathy, is included in informal learning environments in ways not normally considered in institutional teaching.

Resnick (2007) says that

> “the [connected] ‘kindergarten approach to learning’- characterised by a spiralling cycle of Imagine, Create, Play, Share, Reflect and back to Imagine — is ideally suited to the needs of the 21st century, helping learners develop the creative-thinking skills that are critical to success and satisfaction in today’s society.” (Resnick, 2007, p.1)

This seems particularly relevant today because of the increasing dependence on the integration of technological and creative skills.

There is some criticism of integrating these skills as Davies and Guppy (1997) discuss, that encouraging maker attitudes and work ethics will produce a generation of entrepreneurial workers who are equipped for twenty first century economies. Lindter, Bardzell and Bardzell (2016) question the motivation of venture capitalists and critical scholars who are invested in the idea of making as an intervention in education. There is an anxiety of what maker education may do when it is attached to a neoliberal capitalist agenda. There are two opposing groups that are advocating learning through making- those dedicated to an improvement in the inclusivity of education and those who see the entrepreneur as the most desirable future worker, who is responsible for their own conditions, pay and welfare. This scenario of two opposing interested groups is particularly evident in the way western scholars see the maker movement compared to how Chinese scholars see it. (Lindtner et.al., 2016) However, despite the perceived possible future worker exploitation, the literature still suggests that experiential learning is more effective and inclusive and therefore it is worth exploring and researching further.

Online communities, ‘builder’ gaming and learning

Many children in western cultures have a particular knowledge and affinity with online making, planning, 'building' and shared visual 'commons' through games such as Minecraft. Their online sharing allows players to visit, interact with and change their friends' designs or those by celebrity 'vloggers' such as Joseph Garrett (Stampy Cat). While their Minecraft 'architectural' designs stay within the online space, how this may impact on future design education, based on children's developed understanding of processes such as CAD or digital making have yet to unfold. According to Delaney (2016, p.1) “in Minecraft, players build their world around them by removing blocks on a regular grid. Today's children enjoy Lego, but seem far more inspired by Minecraft.” In the case of the Block by Block project, online children's communities are utilised. Discussing this, Schkolne (2016, p.2) said “groups of young people gather for a workshop where, collectively in Minecraft, they together plan and design a space.” Going further, the community oriented creativity might impact the future of architecture as there is a growing opportunity to co-design public spaces. For those growing up co-designing and co-producing online, an effective collaborative approach to design in the real world seems a natural progression.

Combining the positive aspects of making and digital connectivity is ‘digital craft’, which includes 3D printing technologies. These have the ability to “retain the soul of the material and the skill of the human hand, while also benefitting from the precision, efficiency and increasingly unrestricted structural parameters of digital design and fabrication.” (Johnson, 2014 p.16) This is particularly evident within the Wee Replicators clubs where children particularly utilise 3D pens, a tool which gives a fairly instant, tangible 3D outcome. These are used in combination with 3D printers and CAD lessons.

Weber suggests that “children's play flows easily on and off line, in and out of roles, weaving back and forth from the imaginative to the actual. It is in this blurring of boundaries between physical and cyberspaces, between the virtual and the actual that children create play spaces for themselves.” (Weber & Dixon, 2010, p.104). Increasingly this is being facilitated through affordable mobile computing (phones, tablets and pads) in which the device facilitates “the collaborations between students’ which 'transform the spaces in which students work.” (Fisher, Lucas & Galsyan, 2013. p. 165) This has implications not only for the way that visual design may be taught using the tools of CAD, but also the actual spaces in which engagement and learning may take place.

Children and digital technologies

Contemporary western children, with their understanding of digital and online technologies, belong to a global community often through their online gaming. This can be, even more so than the communities in their physical locale.

Despite the profusion of information and the learning and social opportunities available online, certain things cannot be taught, learned or achieved as well as they could be in a child’s physical reality. These include the digital making of physical items created by 3D printers or other making technologies, often provided in open access ‘Fab Labs’ and ‘Maker Spaces’. These are places where the public, often with the input of a ‘mentor’ rather than formal ‘teacher’, can make and realise their own designs. The types of equipment provided in these spaces can include different types of 3D printers, laser cutters, CNC routing machines and sewing machines. There are some companies who offer these making opportunities as services, including 3D Hubs, who claim that if you have a 3D file, you can upload it and it will be 3D printed and delivered to you within 48hrs. (3D hubs, 2018. However, few, if any of these services are aimed at children and most lack the learning stage that leads up to the creation of the necessary 3D file.

These maker spaces, which also often combine informal group classes with the one-off, open-to-the-public bespoke service, although primarily aimed at adults, are beginning to invite children to explore and experiment. As Dougherty (2014, p.75) explains, “we need adults to facilitate and create maker spaces in their communities that are accessible to all children." Once children see themselves as learners who have good ideas and can transform these ideas into reality they become empowered.

Open access digital fabrication facilities, through unstructured group and individual projects, can provide innately creative group based spaces, collaboration and imaginative problem solving, while traditional school models can emphasise uniformity and predictability. By welcoming online communities and encouraging the creation of child accessible maker spaces and groups in all local communities; the implications for technology, in the context of making and learning, can expand beyond parental concern of physical social isolation and computer dependencies. It can, potentially, replace the concept of technology as an artefact or function with the ideas of what it might facilitate on a personal and social scale. (Mizen, Hutchby, Pole, Moran-Ellis & Bolton, 2001) One of the few examples of maker spaces that combine classes for adults, after school clubs and also an integration of their practices into the curriculums of several schools are the Curiosity Gym in Mumbai. They say "DIY [handmade utilising digital tools] activities and processes reflect your personality. DIY is a maker culture that discovers simple processes to generate outstanding projects of great utility. It discovers the maker in you and encourages you to take up challenges to create useful objects. You can learn faster from the hands-on experience." (Curiosity Gym, 2018. p.2) They also offer the following graph of 'DIY' learning that occurs in their various classes and workshops put together from Bloom's Taxonomy and their own observations.

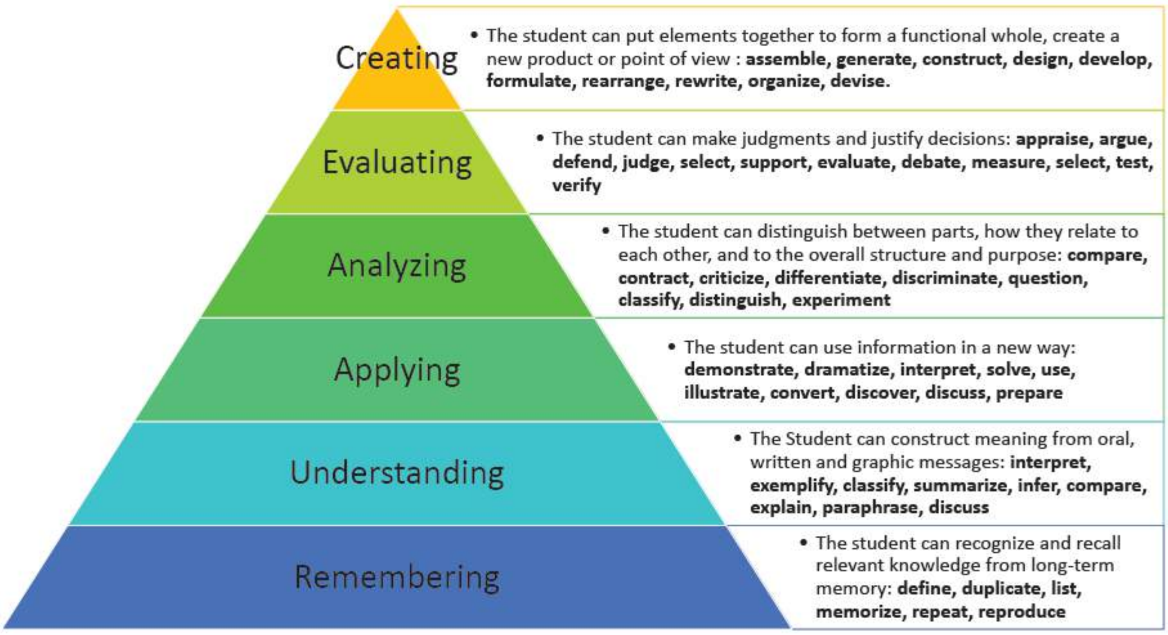

Figure 1. Taxonomy of learning at the Curiosity Gym open access maker space

Lipson and Kurman (2011) discuss 'earl grey syndrome' which is the problem of only being able to desire what one already knows exists and therefore not contributing to new ideas and solutions. Perhaps children can overcome this problem more easily if they grow up without having limitations put on their imagination by their understanding of what is possible. Children appear to have a fluid, open mindedness to what can be achieved through digital, online and technology that they can easily manipulate. Their online relationships, whether they are with peers, constructed groups or with celebrity vloggers, come naturally to them and will be impactful on how information, including 'design files' created on CAD, is shared, now and in the future. Perhaps more so than with links between 'analogue' play, including adventure playgrounds, (Lambert and Pearson, 1974) wooden blocks, Montessori, (1964) and Lego (Rogers & Portsmore, 2001) and measured learning outcomes, 'hobby' led digital designing and making, in informal and institutionalized settings can blend children’s real interests and skill acquisition.

Methodology - Observational research of children in a digital making club

A research protocol was designed and agreed with the parents of the children involved, which also adhered to Edinburgh Napier University research integrity protocols. Informed consent was given by all parents of participants for them to take part in the research and have their photos taken. The children were also spoken to and made aware that they could withdraw from the study at any time.

This research draws upon primary sources, principally the observation and analysis of children who attend 3D printing clubs hosted by one of the authors, Denise Allan. These clubs are aimed at children just starting their formal school education, from the age of six. The clubs are informal and relaxed to allow a great deal of creative freedom. The children can be observed in as natural a state as possible. They have access to 3D printers, CAD software and 3D printing pens to allow them to explore the technology and design process in different ways. They can choose to work together or alone, and can participate in the group discussion in an unforced way. The clubs are regular, weekly events to ensure that the excitement and novelty of the access to these tools does not overshadow natural behaviours and obscure what can be learned about the implications for learning and open access fabrication.

The following observation was achieved by preparing, in advance, the environment and the situation. The children grew to accept Allan as part of the group and were accustomed to her taking photographs frequently. This allowed the observation to be conducted by participant observation, using photographs as field notes. By keeping the environment as normal as possible Allan was able to actively see and understand the motives of the children and keep a rigorous record of the events and behaviours as and when they occurred. (DeWalt & DeWalt, 2002)

This case study began with informal observations of over a hundred children that attended the workshops at the Wee Replicators 3D printing clubs, with work by two boys disseminated in this paper. These clubs provide children with access to a 3D printer, 3D printing pens and Google SketchUp modelling software. This case involves a six year old and a ten year old who, at the point of this observation, had both been attending the 3D printing club for almost six months. This observation took place in March 2016. The boys sat down at two computers and opened up the modelling software. (See Figure 2) Neither of them had used the software before and so they were both given a quick demonstration at the same time, they were briefly shown some of the tools, which included the pencil tool, the rectangle tool and the push-pull tool. Both boys started as soon as the demonstration was over.

This particular case was chosen to represent the many occurrences of the same phenomenon as there were fewer differences between them and so conclusions could be drawn more efficiently as they were the same gender, had the same experience of 3D printing and they both had no experience of CAD.

Figure 2. The two boys using Google SketchUp

Primary Research Observations

The day that the case study was undertaken at the 3D printing club, there were eight children attending. Therefore, the observation was not constant and instead, the boys were observed every 5-10 minutes for a few minutes. Approximately 10 minutes after starting, the six year old shouted for help. It was not possible to help him immediately as other children needed attention. Therefore, it was about 5 minutes before he could get assistance but by that time he had already worked out how to fix the problem he was having. The problem he had was that when he was using the push-pull tool, the shape was not solid and appeared to be hollow. The software highlights this by making the object light blue instead of grey. The six year old had recognized this as a problem and worked out how to fix it.

Conversely, when viewing the work of the ten year old, it was clear that he had the same problem (see Figure 3). Instead of stopping and trying to fix it, he had carried on, ignoring the issue which at that time was starting to cause him problems. He had a Lego figure next to the laptop and was clearly copying the structure but making it the shape of what might be thought of as a traditional robot. As he had not fixed the push-pull problem, he was having difficulties making the indents in the feet of the robot so that it would click onto Lego bricks. The six year old had drawn a series of blocks pulled out from one another, (see Figure 4). He said that it was, “a house from the future”. He was asked if that is what he was making from the beginning and he replied, “No, it just turned into a house.”

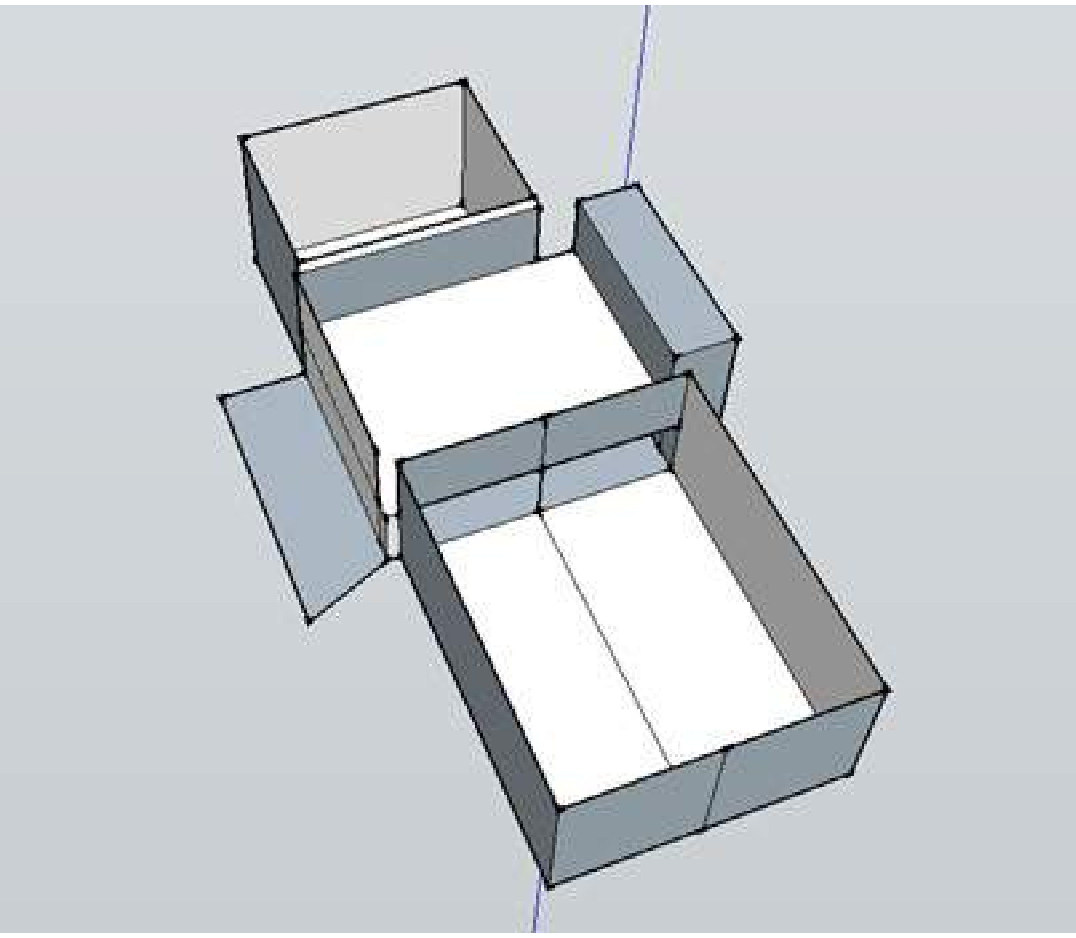

Figure 3. Ten year old's robot model was not solid due to problems with the push-pull tool.

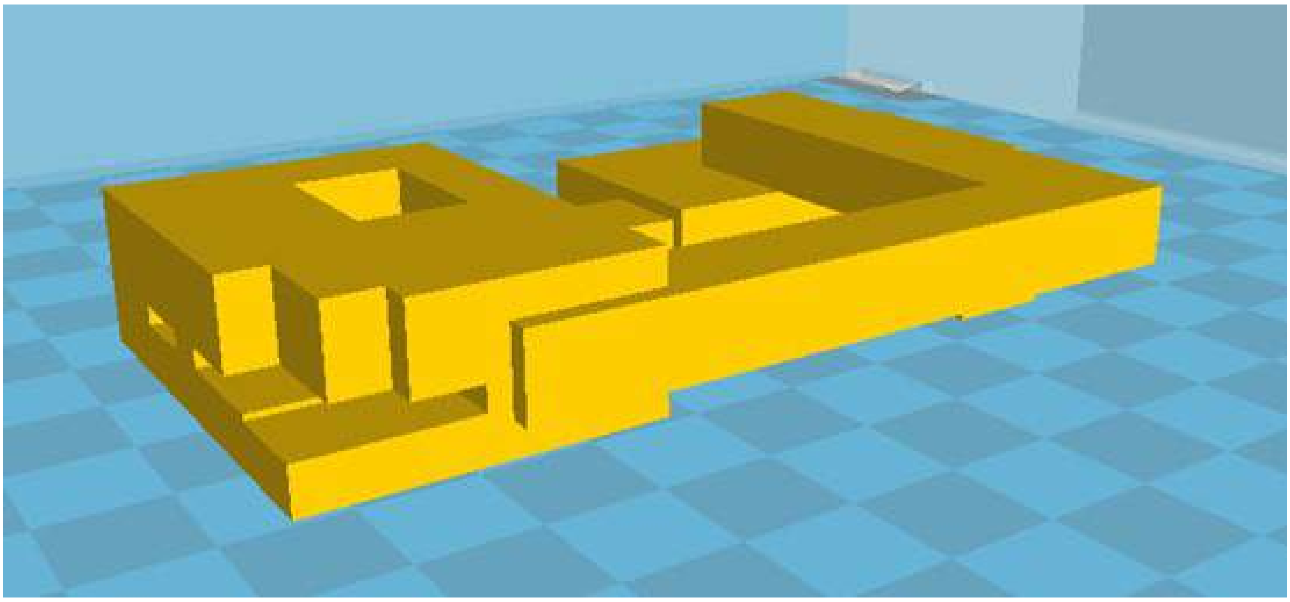

Figure 4. The six year old's model was constructed using rectangles pulled in and out of other rectangles.

Both boys were familiar with 3D printing and the process to prepare a model for printing. The six year old asked that his “house from the future” be printed with supports so that it would, “have the stringy up and down bits”, which he liked the look of on other items he had seen printed. The boys saved their CAD drawings and asked for them to be printed in time for the next 3D printing club. The six year old's model was printed as he left it, as it required no alterations. The ten year old's model required significant changes in order for it to be 3D printed, (see Figure 5).

Figure 5. Final model of the ten year old's robot.

Findings

Learning about CAD can sometimes be a repetitive, drawn out process. Traditional design education in Scotland, in a formal context generally starts in 3rd year of secondary school when students are approximately 14 years old. Through the personal experience of the author, it seems that to learn both technical drawing and CAD skills in school and university, students are generally set a project to copy an existing design. (Solidworks, 2016) Through copying products students are able to see and feel what the object feels like and from an educational point of view, educators can pick objects, which ensure students learn key skills such as fillets (how to round edges and corners of a model). This appears to be a legitimate learning technique and has proved to be successful, although not necessarily enjoyable.

Considering this case, perhaps while learning CAD children should be encouraged to explore the tools available and try them out, and not be encouraged to replicate an existing product. The child, who experimented with the tools without a particular object in mind, was able to successfully create an aesthetically pleasing model, (see Figure 6) Alternatively, the child who attempted to copy a Lego figure created a model that looked recognizable, but it was not viable as a 3D printable object. This observation is supported by the concept that learning by copying or from a book is not always as successful as learning by experience. When learning through experience, the learning is more memorable and connected as the person had to act off his/her own accord to achieve an outcome instead of merely reading or copying a method. (Jakubowski, 2003) However, this method may only be applicable for children and or beginners for a short time. If they are to go beyond basic CAD skills they will likely have to take a more structured approach to learning specific skills in order to achieve a particular task. However, this can still be achieved in a constructivist way. (Thirteen, 2016)

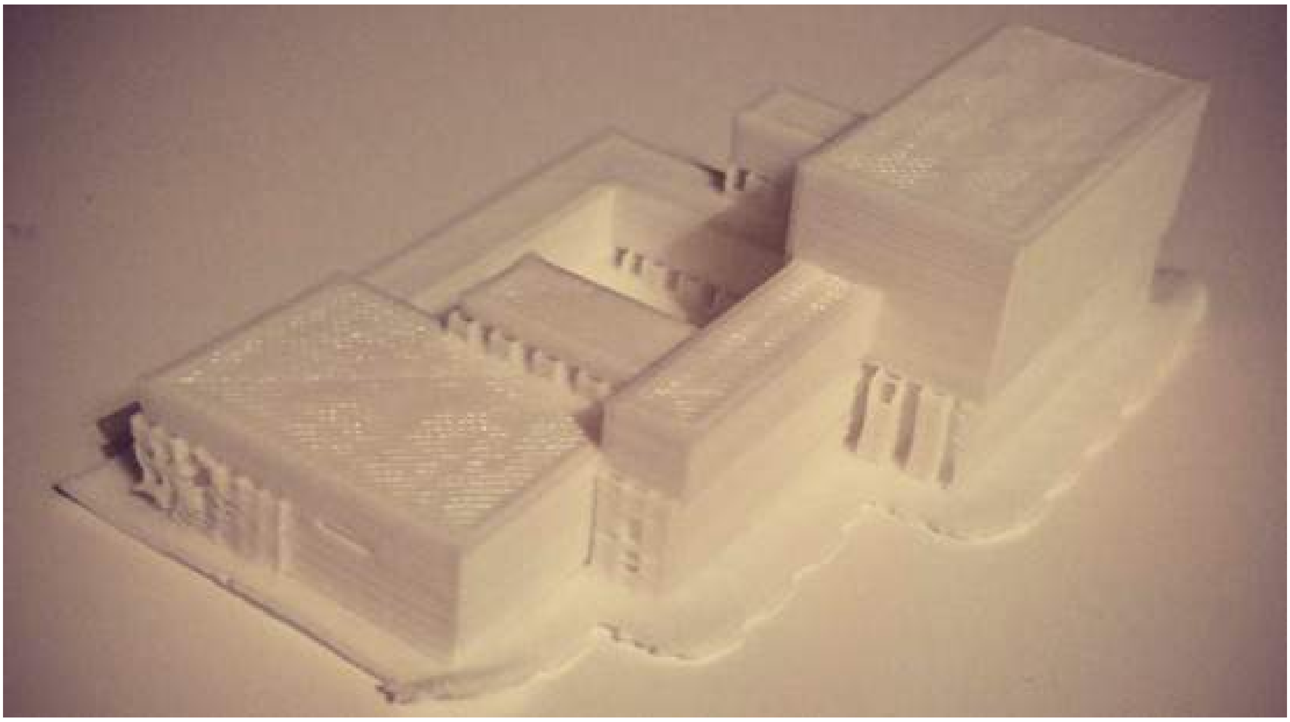

Figure 6. Final printed model of the six year old's 'house from the future' including the support material that he wanted to leave on the model.

In terms of problem solving, the child who experimented was able to solve his problem when help was not immediately available. He had no particular goal in mind and so was able to go backwards to try something else. However, the ten year old was focused on creating a robot and when he came upon the same problem, instead of stopping to fix it, he carried on making his robot, perhaps thinking that he would fix the problem when he was finished. This illustrates the idea that experimentation is a legitimate method for problem solving as it encourages an iterative process which allows a person to repeat a task as many times as necessary to achieve the desired result. This can be likened to the theory of multiple-try feedback. This is a system often used in mathematics, where children are given the opportunity to answer a question or problem until they get the correct answer. It can also be likened to the serendipitous aspects of traditional craft. This differs from a multiple-choice method of learning. During the processes outlined in this study, children are provided with the opportunity to find the correct answer or solution for him or herself, and not to simply be told what the right answer or solution is. In addition to this, they are not given a selection of possible correct answers or solutions, allowing their solutions to be more innovative. (Attali, Laitusis & Stone, 2016; Rossella, Noe & Rossi, 2014). This also often takes place in 'builder' gaming situations when breaking down 'built' structures can be easily reconstructed without there being any repercussions. By discovering how best to facilitate and encourage the learning of CAD skills at a young age, fabrication tools will have a far greater opportunity to be culturally significant, democratized and to become open source on a wider scale.

Conclusions

By analysing the educational benefits of informal shared design practices and digital fabrication method, they may be seen as tools to be used in more institutionalised learning environments of the future. Digital making and informal learning environments have been shown to be a positive influence on the innovative outcomes of the participants in this study and reviewed in the literature.

This study aimed to investigate how informal club settings and the devices used within them affect the outcomes of the children's learning, designing and making experience. In doing this, the case study showed that children who explored maker tools without a particular objective had a more successful learning experience as they found solutions to problems as they played, whereas the children who had an end point in mind tried to get there while ignoring the problems they had encountered. The learning which occurred extended beyond the skill to use a particular tool but also included the ability to persevere, communicate with peers and mentors while also picking up other core skills such as spatial awareness, measuring, adding and subtracting. The informal club setting lends itself well to this type of learning as it is extracurricular and therefore not constrained by the learning targets placed on institutional facilities. However, perhaps with more research and substantiated evidence educational policy makers will trust that targeted learning objectives are achievable using informal learning strategies such as those described in this article.

The study also considered the similarities and differences between how children use and are frequent participants in online virtual maker environments such as Minecraft and how they played and participated in digital making clubs with access to digital making technologies such as 3D printers. One of the most obvious outcomes of children being part of online maker communities was their perseverance to keep trying until they achieved their desired outcome. In the digital spaces online, children can easily press undo until they manage to do what they intend to. This ability to start again as many times as necessary has led to a perseverance which has moved into real world maker-spaces too as children seem to trust that they will get 'it' eventually. In the case discussed in this paper one child utilised the 'undo' function to effectively find solutions while the other assumed that there would be a solution and did not worry that his model temporarily did not look right. Although the first child displayed the desirable learning through exploration, the second child demonstrated a trust in their ability to make it work, whereas children who are not part of online maker games may have given up when it started to go wrong. Additionally, although not specifically discussed in this case study, online maker gaming has resulted in children who effortlessly collaborate with others and see co-design and co-production as the way that design and making happens. This is evident throughout the digital making clubs run by 'Wee Replicators' as children work together, help each other and give each other advice without hesitation.

The intention of this research was to provide some preliminary outcomes which could be used in institutional education environments. Therefore, the following guidelines have been developed from the findings:

1. Allow students to spend time exploring the topic of their lessons to allow them to see connections and make the subject relevant to their interests and hobbies which will make their learning more personal and meaningful to them.
2. Give students the freedom to use digital technology and maker tools for their own personal projects. This builds passion and responsibility in students making them feel capable and valuable.
3. When a child comes up against a problem avoid giving them the solution. Instead support and encourage them to find solutions for themselves.

The open-access aspect of maker spaces, that brings together diverse online and physical communities, is also worthy of further investigation. Gershenfeld (2012) said,

"Fab Labs seek to balance the decentralized enthusiasm of the do-it -yourself maker movement [the online community of enthusiasts for this subject] and the mentorship that comes from doing it together. After all, the real strength of a Fab Lab is not technical; it is social. The innovative people that drive a knowledge economy share a common trait, by definition, they are not good at following rules. To be able to invent, people need to question assumptions. They need to study and work in environments where it is safe to do that." (Gershenfeld, 2012, p.51)

Other studies have had noticeable outcomes with Blikstein (2013) concluding that "digital fabrication and 'making' could be a new and major chapter in this process of bringing powerful ideas, literacies and expressive tools to children." (Blikstein, 2013, p.2) Posch, Ogawa, Lindinger, Haring and Hortner (2010, p.257) stated that "Creative prototyping, shared creativity and the supportive underlying infrastructure play an essential role in the motivation of children and novice users". From research gathered to date, the skills all users may acquire through their interaction with the informal learning through digital making technologies include team work, research skills, communication skills, design thinking, technical drawing skills, entrepreneurial skills, computer skills, creativity, innovation and cooperative learning, all in a place that is 'different' from traditional learning environments. Observations of online 'creative' communities, maker spaces and informal learning environments for children, including those created by Allan and online children's' community projects such as Block by Block, show that a great deal can be learned from the innovations that occur there. While constructivist teaching, informal learning in unstructured environments originated with Dewey et al, online and digital making technologies, integrated with these approaches, offers real opportunities to develop and enrich education and wider society.

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Learning Engineering through the Flipped Classroom Approach- Students' Perspectives

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Abstract

A flipped classroom approach consists of two distinct parts: direct on-line instruction in the students' own time and at their own pace, and interactive group learning and problem-solving activities in scheduled classes. This approach has the potential to suit theoretical and practice-based courses such as technology education. This article outlines a study on students' views of using the flipped classroom approach to learning from the perspective of first and second year engineering students undertaking a module of learning in Dynamics. Engineering, like many technology related courses is both theoretical and practical in nature. The study investigates students' views of the use of the flipped classroom approach using focus-group and individual interviews after they had experienced it. The flipped classroom approach facilitated students' exposure to theoretical ideas in their own time through online lectures, thus maximising time for problem solving activity with their face-to-face lecturer support. This research suggests several key factors within two broad categories that students felt influenced their learning. These categories were identified as Perspectives of Lecturer Behaviour and Perspectives on Student Behaviour. The article concludes with a number of recommendations aimed at improving the teaching and learning experiences for students in the flipped classroom and makes links to the potential applications for other design and technology education disciplines.

Key words

engineering education, flipped classroom, collaboration, student perspectives, teaching and learning

Introduction

There is significant pressure on tertiary educators to improve the efficiency and effectiveness of their teaching and to engage with innovative teaching methods using digital technologies, however understandably many have no expertise or interest in educational pedagogies (Serdyukov, 2015). This article outlines a study undertaken by academics from three fields of learning (E-learning, teacher education and engineering) and investigates students' views on aspects of the flipped classroom approach. The research builds on recent literature in the field of innovative teaching approaches and adds to the body of knowledge around student voice about teaching approach. The article concludes by recommending a number of behaviours for lecturers and students to enhance learning during this pedagogical approach. The study, qualitative in nature was part of a wider mixed methods study on using a flipped classroom approach to learning in a university engineering programme.

The flipped classroom approach, although first introduced as early as 1982 (Baker, 2000) has become popular in recent times in many educational institutions due to advances in educational technologies, pressure to improve student performance, a willingness to challenge established teaching methods, and fiscal pressures within universities (Carpenter, Blythe, Sweet, Winter & Bunnell, 2015; Serdyukov, 2015). The flipped classroom approach to learning has the potential to provide educators with opportunities of maximizing and increasing the quality of face-to-face instruction as students are asked to come to class having already engaged with course materials. However, it is important to consider students' views of the approach to ensure the best outcomes for students and their learning.

This study investigated engineering students' perspectives of the flipped classroom approach used to teach a summer school paper in two consecutive years. The content included foundational engineering dynamics and was taught to first year students as a part of a four-year university degree programme in New Zealand. It was the lecturer's first encounter with the flipped classroom approach and the aim of the study was to ascertain the success of the approach from the students' point-of-view in terms of their experiences about the approach used. The article includes a range of participants' recommendations to improve the flipped classroom experience.

Motivation for the Study

There is an increasing body of literature reporting a range of success with the flipped classroom approach (Blair, Maharaj, & Primus, 2016; Gannod, Burge, & Helmick, 2008; Lavelle, Stimpson, & Brill, 2013; Love, Hodge, Grandgenett, & Swift, 2014). Recent changes and pressures in tertiary teaching sector have led to an increased uptake of alternative methods of teaching and learning (Blair et al., 2016; Comber & Brady-Van den Bos, 2018; Serdyukov, 2015). Today's students are demanding more from their educational institutions. In the information age, they are connected and aware of what others are getting. They can compare and contrast approaches and therefore request access to information in a variety of mediums. Thus, institutions must support and improve learning experiences for their students to remain competitive. There is also increased pressure from qualification authorities and governments for universities and other tertiary institutions to perform more effectively and efficiently (Bishop & Verleger, 2013; O'Flaherty & Phillips, 2015).

To vary teaching and improve experiences for engineering students, a flipped classroom approach was trialed during the condensed summer school programme two years in succession. This study aimed to determine the students' perceptions and experiences of the approach with the aim to make further improvements, and recommendations for similar problem solving and practically based courses.

Literature Review

Flipped Classroom Defined

A flipped classroom approach consists of two distinct parts: direct on-line instruction at the students' own time and pace, and interactive group learning activities in scheduled classes (Bishop & Verleger, 2013; Comber & Brady-Van den Bos, 2018). Course content can be presented in the form of readings, videos, graphical presentations or quizzes (Blair et al., 2016; Hanson, 2016; Lavelle et al., 2013). These online 'lectures' are followed up with lecturer or teacher run workshops within which students engage with the recently delivered course materials, thus putting theory into practice. Such sessions typically include elements of interactive, collaborative and applicative engagement in problem solving (Bishop & Verleger, 2013; Hanson, 2016; Lavelle et al., 2013).

Rationale for and Characteristics of Flipped Classroom in Tertiary Education

Students in the 21st Century require a wide range of 'soft' skills and knowledge. These skills best occur in authentic learning situations and include greater collaboration, communication, problem solving and critical thinking (Snape, 2017). Utilisation of the flipped classroom approach has increased in recent years in response to this change in learning practices of students who also increasingly tend to access information via information and communication technologies (ICT) (Hanson, 2016; Serdyukov, 2015). Blair and colleagues (2016) and Serdyukov (2015) suggest that recent ICT advances have assisted the facilitation of the shift in tertiary teaching from the traditional teacher-centred approach to a learner centred approach.

The shift to learner-centred pedagogy aligns with sociocultural learning theory based on the works of Vygotsky, Piaget and Dewey (Serdyukov, 2015) and socio-constructivist theory (Snape, 2017). Many of Vygotsky's (1978) ideas, particularly the Zone of Proximal Development, are directly relevant to student learning. Sociocultural approaches to education and learning are different from approaches that are more traditional. In sociocultural theory, focus is on the roles teachers or more capable peers play in learning with an emphasis on peer group interactions and collaborative learning (Daniels, 1996; Richardson, 1998). Snape (2017) suggests that socio-constructivist learning is self-regulated, situated in social, contextual and cultural environments, and collaborative in nature. Clarke (2014) states that cognitive ability is able to be grown, as opposed to being fixed as was understood in earlier times. Allowing students, the flexibility to learn in differing ways using a range of strategies increases opportunities for a wider range of students to achieve.

Online learning, can be individualised, however it is more likely to be successful when taking place within learning communities (Serdyukov, 2015). The concept of guided participation in activities is essential to students' apprenticeship into thinking within new contexts (Bishop & Verleger, 2013; Rogoff, 1990). These ideas are particularly relevant to the flipped classroom approach as learning occurs both independently and through collaborative activity (Lavelle et al., 2013). Course content is engaged with independently, while subsequent scheduled classes offer opportunities for collaboration, higher-level thinking, and exposure to varied ideas and understandings from peers, as well as engagement with authentic practical activities that apply and extend on-line lecture materials. Choi (2013) states that successful engineering education must develop real-world skills. The flipped classroom works well in lab-based classes (Lavelle et al., 2013) due to the practical and interactive nature of laboratory sessions. Hence, the increased direct student-teacher engagement can facilitate better mentoring of practical skills. This mentoring can occur on a needs basis as lecturers' time spent on lecturing occurs before scheduled class times (Lavelle et al., 2013).

Mayer (2002) suggests that the flipped approach to learning facilitates long term retention and application of course material, as opposed to simple transfer of knowledge and facts, as is the case in traditional classrooms. Lavelle et al. (2013), Johnson and Renner (2012) and Blair et al. (2016) identify a number of other advantages in using the flipped classroom approach. These include developing critical and higher-level thinking, more opportunities for collaborative work, and increased face-to-face interaction with the lecturer, student schedule flexibility and ability to review and or pause lecture materials when needed. Learning is easily modified for a diverse range of learners as the video and other pre-lecture materials can be planned to ensure the needs of all students are met, including those with disabilities. Post viewing reflective activities can also be developed for formative assessment purposes to enable the lecturer to ensure following workshop activities meet the specific learning needs of the students. Choi (2013) states that an ideal educational environment provides students with specific and immediate feedback. The flipped classroom approach enables this if on-line lecture materials are relevant, provision is made by the lecture for reflective feedback from students, and then workshop activities are carefully designed to meet emerging student needs with opportunities for immediate feedback for students as they work through them.

Sociocultural conflict theory is also relevant to the flipped classroom approach to learning. It suggests that discrepancy or conflict best sparks cognitive development. Socio-cognitive conflict theory identifies conflict as an essential ingredient to bring about cognitive change. Doise and Mugny (1984) have demonstrated that students working in pairs solve problems at a more advanced level than those working by themselves regardless of the ability of the partner. They found that when students were challenged with an alternative opinion to their own, student performance improved, regardless of the validity of the opposing viewpoint. The conflict can only be resolved if cognitive restructuring takes place, and therefore mental change occurs because of social interaction. The social, collaborative and problem-solving nature of the practical workshop activities used in the second part of the flipped classroom approach are a perfect opportunity for students to learn through debate and discussion while engaging in relevant problem solving.

Baker (2000) identified key characteristics of successful flipped classroom implementations. These include a change in role for the teacher to a 'facilitator' rather than a 'director' of learning, and a reduction in lecturing. Increased use of active learning with a focus on understanding and application and the provision of student control are also characteristics as well as a greater sense of student responsibility over learning. Students have greater opportunity to engage with their lecturer one-on-one, and the opportunity to learn collaboratively with peers. Gannod et al. (2008) reiterate the need for facilitated collaborative learning. They note that groups of students must achieve consensus to solve particular tasks. This means considerable higher-level thinking, discussion, debating and repositioning of ideas may be necessary. Proper facilitation of the workshops shows students that their lecturer is interested in them and their learning, but failure to do so may lead to disengagement (Choi, 2013). Popular at first with subjects from the humanities Carpenter et al. (2015) suggest that recent technological advances have made the approach more popular with Science, Technology, Engineering and Mathematics (STEM) based courses.

The flipped classroom approach holds a number of challenges and disadvantages. Mason, Shuman, and Cook (2013) identified three major difficulties with the flipped classroom approach 1) time computation, 2) student discomfort with taking responsibility for their own learning, 3) discrepancies in the literature about the flipped approach in some courses. Johnson and Renner (2012) suggest that a strong work ethic is needed for success in the flipped classroom environment both from the teachers' and students' points-of-view. Furthermore, not all students will be inclined to view the materials prior to their workshop classes. Also the development of the materials is labour intensive (Lavelle et al., 2013) for lecturers and video materials may not very easily corrected or modified. Mason et al. (2013) state that their biggest concern is flipped classroom pedagogy. The approach assumes that students have on-line access, this can prove difficult for students in rural areas and the assumption that students have the pre-requisite skills and web-based technology necessary for successful implementation. This could mean students become disengaged and leave their courses (Carpenter et al., 2015). Many university campus classrooms have been designed for a traditional lecture approach to teaching. This setting makes mobility and collaborative work desirable in the flipped approach, a challenge (Carpenter et al., 2015). Therefore, before undertaking a significant shift to a broad ranging flipped approach it is critical for universities to explore the feasibility of this approach.

Students' Perceptions of the Flipped Approach to Learning

Students' perceptions of the flipped classroom are particularly varied (Blair et al., 2016; Hanson, 2016; Johnson & Renner, 2012; Love et al., 2014; Nguyen, Yu, Japutra, & Chen C-H. S., 2015). Blair and Colleagues (2016) report that engineering students were keen to continue with the flipped approach after engaging with it. Students' perceptions of the flipped classroom approach was influenced by the quality of the course content materials used (Blair et al., 2016). Hanson (2016) reported several advantages, these included increased understanding through dialogue in the face-to-face component, wider and deeper thinking, the ability to pause and replay the online lecture material and the flexibility of time to avoid conflicting commitments and students also acknowledged a reduced sense of isolation and disengagement. Students in several studies acknowledged that the flipped approach required different teaching and learning approaches to ensure individual grades did not suffer and recognised the approach required self-discipline and a change in study habits. They also recognised that the flipped approach was more efficient than more traditional approaches (Blair et al., 2016; Hanson, 2016; Nguyen et al., 2015; O'Flaherty & Phillips, 2015).

Nguyen et al. (2015) reported that students appreciated being able to talk to their peers while viewing the online lecture materials. They felt that dialogue and engagement with peers was beneficial and an important aspect of good teaching practice. Students also recognised engagement in the recorded online material as critical (Blair et al., 2016; Nguyen et al., 2015; Pierce & Fox, 2012). Students in several studies valued the reviewability of the materials and the ability to engage with course materials before the workshop (Blair et al., 2016; Love et al., 2014; Pierce & Fox, 2012). Hanson (2016) reported that not all students were positive about the change in approach. One key aspect of Hanson's study was that students felt that the process and potential benefits of the flipped classroom approach needed to be explained to them clearly from the beginning. This concurs with a study by O'Flaherty & Philips (2015), where students felt that they needed to be told that attendance at both components of the flipped approach (independent lecture and workshop) were necessary for success in the course. Nguyen (2015) and Zhu, Y., Wing, A. & Yates, G. (2016) suggest that students need to understand the value of self-preparation and self-control before engaging in flipped education.

Methodology

This article reports on an interpretive qualitative study, which was part of a greater mixed methods study to investigate students' perceptions of the flipped classroom. The findings of the study are reported as a mixed cohort of students who participated in the flipped classroom over two subsequent summer schools in during the 2014-2016 period. The theoretical paradigm of *interpretivism* is the study of meaningful social action and is predominantly concerned with achieving understanding through feelings and world views (Neuman, 2000). The central aim of the interpretive paradigm is to understand the subjective world of human experience while maintaining the integrity of the subject. It also aims to understand how people construct meaning in a natural setting (Neuman, 2000; Taylor & Bogdan, 1998). This approach enables researchers to examine students' perspectives on how they interacted with their lecturer, peers, technologies and other culturally situated tools to construct knowledge and understanding in dynamics engineering.

The study occurred over a two-year period and investigated the views of 18 students who undertook the flipped classroom approach for one summer semester paper. The sample size is small so results should be viewed accordingly, however student voice enables deeper understandings to emerge that may not be evident through quantitative data. All course members were emailed and asked if they would like to participate in the study. In the initial email and again on the participant consent forms anonymity for all students was guaranteed. All but two of those who agreed participated in one of several semi-structured focus group interviews, however scheduling limitations required two individual interviews. Either one or two of the authors undertook the interviews. Interviews were transcribed and subsequently coded and analysed to identify themes and several key factors that influenced students' experiences and perspectives of the flipped classroom approach.

Aspects of this research were educationally sensitive (Cohen & Manion, 1994) as one of the authors was the course lecturer and in a position of authority over the students. Due to this ethical consideration, this researcher did not undertake any of the interviews, and only received anonymised interview transcripts. Semi-structured interviews are designed to explore how, people behave, what they do and why (Taylor & Bogdan, 1998). One of the advantages of the focus group is that they are likely to yield insight not otherwise accessible in other forms of interview as the participants are prompted by other's contributions (Cohen, Manion, & Morrison, 2001). A noted disadvantage of focus group interviews is that they must be interpreted in terms of the group dynamics as this could well impact on the contribution of some of the participants (Taylor & Bogdan, 1998).

Findings

The findings in this study support the findings of a number of other studies (Comber & Brady-Van den Bos, 2018; Pierce & Fox, 2012). In general, most students responded positively to the flipped classroom experience, however, one student in this study was notably negative. This study further analyses aspects of the practice that impacted students' views. The data suggests that student impressions of the influences on their learning in the flipped classroom can be divided into two broad categories: perspectives of lecturer practice, and perspectives of student practice. Each exhibited a number of key factors summarized in Table 1. Some key factors, such as student responsibility for time management, or working collaboratively were regarded both positively and negatively across the cohort. The description of each factor is supplemented by a range of recommendations that were derived either directly or indirectly from student comments.

Table 1: Broad Categories and Key Factors of Students' Perceptions of the Flipped Classroom Approach in Engineering Education.

Perspectives of Lecturer Practice	Perspectives of Student Practice
• Course Materials • The Process • Lecturer Approach • Preparation of Students	• Reviewability • Independence • Time Management • Working Collaboratively

Students' Perspectives of Lecture Practice with Associated Recommendations

Course Materials

A number of students commented that course materials were easy to use in their own time and at their own pace within the designated online learning environment (based on the Moodle platform); however nearly all of the students experienced frustration because of a number of errors in the video material. Students recognized that mistakes would be time consuming to fix, some even offered a solution:

> *Have you guys watched The Khan Academy, so… [the lecturer] was complaining that if he has an error in his recordings then he has to start from scratch. He was having editing issues, but what Sal [in the Khan videos] does he just puts a little text box at the bottom and says, hey look, this is wrong and this is what I meant to say. It would have reduced the time and effort that we spend quite dramatically (Student D).*

Students appreciated the emphasis on collaborative problem solving during workshops and the direct connection to the online material each week. A number of students would have preferred earlier access to lecture material in order to prepare adequately for workshops. "Maybe write a list of questions out and then you know what you will ask at the next tutorial. Just keeping up-to-date" (Student N). Others mentioned that they would like a variety of materials used in the on-line environment. One student suggested having an additional online forum as a part of the course. Some students experienced frustration with the on-line materials because of their length and the time taken to watch it thoroughly. "For me it was at least three hours in the evening after I came home from work…you finish that and you are exhausted" (Student A).

Student comments with regards to course materials give rise to a range of recommendations; materials should be presented to students in a varied and balanced delivery, deploying a range of teaching and learning strategies to ensure that students remain engaged in the course. Such strategies could include: lecturer developed videos, use of existing materials available on the internet (such as Khan Academy), on-line forum, post video quizzes, authentic collaborative problem solving and activities using innovative ICT tools as they emerge such as Padlet or Google Sites.

In addition, students need to have confidence that the material with which they are engaging is of a high standard, succinct and engaging. Some sort of professional assistance for staff as they develop video and other in line materials would be valuable. Furthermore, based on student comments on how and when they engaged with the materials, making workshop and video lecture material available to the students well in advance will enable them to better manage their time and self-paced learning. Along with this a very clear schedule of the face-to-face workshops with a detailed outline of content is recommended so that students are adequately prepared for each workshop.

The Process

Most students were positive about the process with several indicating that they experienced increased engagement because of it.

> When you're taking notes in real time lectures you focus more on taking notes and you don't have time to digest the information and they find it quite useful; that [in the flipped classroom] they could pause and think about what they just wrote, and the content sunk in better (Student O).

Over half of the students mentioned that they like the frequency of the tutorials, which were held at least twice weekly during the course. A number of students mentioned the course forced their engagement, while most thought this was a positive aspect; "compared to my first-year grade I was normally [understanding course content] on a higher level so yeah I was more engaged, I was willing to work harder" (Student F). Another student suggested that although the course took more time than the traditional approach she knew the material better and therefore needed less study for the end of course examination.

Three students specifically mentioned the approach led to improved achievement, "I'd say just that the teacher and the way he taught was very effective and reflected in my results" (Student L). Nearly all students were very positive about the collaborative nature of the workshops, the opportunity to interact with the lecturer on a one-to-one basis and liked the small class sizes and the resulting group dynamics. "We were sitting in groups and the girls in my group really helped me out" (Student F), "you kind of need someone who learns with you" (Student F). It is worth noting that the lecturer frequently collected feedback from students (formally and informally), about their views on the effectiveness of the flipped approach and their enjoyment of the process. This was an important part of the process and therefore a recommendation stemming from the findings, as long as subsequent actions rectify students' frustrations.

Lecturer Approach

Students in the study were very positive about their lecturer approach during the course and indicated that they experienced increased engagement during the flipped classroom. Students mentioned that the lecturer's positive attitude, approachability and willingness to provide thorough explanations as important aspects of his approach that assisted them in further developing their understanding during the scheduled workshops. "[It was] easier to get that one-on-one time, easier to get the help you needed" (Student M). "I'd say just the teacher and the way he taught it was very effective, and that reflected in my results" (Student L). Students mentioned that the one-on-one time they had with the lecturer during the workshop sessions was an essential element of the flipped approach that helped them remain engaged and enjoy the process "the classroom was smaller, so it was like a closer connection between the teacher and you" (Student F).

Another aspect of the lecturer approach that the students experienced positively was his dedication and time commitment preparing the course materials. Two students specifically mentioned appreciation of the lecturer's time investment into the process. Some students suggested that the lecturer, as well as develop his own material also access and make use of readily available on-line material. *The Khan Academy* was mentioned several times as an alternative freely available resource that lecturers do not always use: "Lecturers tend not to use that resource [internet], they don't give you links, they don't engage with the thing" (Student A).

Based on student feedback with regards to the lecturer approach, a positive lecturer approach with the belief that all students have the potential to learn is essential. If all students have the potential to learn then it stands to reason that lecturer approach and attitude are significant contributing factors in students' achievement. A growth mind-set to intelligence (Clarke, 2008) will assist lecturers in understanding that their approach to their students and the strategies and material they are teaching has a huge impact on students' achievement.

Preparation of Students

Several students commented that they felt that they should have been better prepared for the process as it involved an entirely different way of working. One of the students explained that this could have been better achieved with the support and facilitation of the lecturer: "You need to purchase that approach with a different approach as well as think about it. You need to explain that material to a person who doesn't really understand. You need to guide them through several courses" (Student A).

A minority of students surveyed preferred the traditional approach. Several students mentioned that after having experienced the flipped approach in this course they would be happy to undertake more courses that use the flipped approach, however many of them identified several limitations in using a flipped approach in more than a few courses at a time. “Running four papers doing a flipped learning would be an immense undertaking, just the time commitment” (Student D).

It is clear from these findings that then undertaking learning through a flipped classroom approach students need to be well prepared for the process. The lecturer has an important role in clearly explaining the process, its rationale, underpinning philosophy and advantages to all participants. Students’ requirements and lecturer’s expectations should be very clearly outlined from the outset. It should not be assumed that students know how to manage their time for effective self-paced learning. Specific time management strategies can be taught and scaffolded timetables provided for those new to the approach.

In addition, gradually enabling students to transition from learning in a traditional setting to learning a flipped environment might be beneficial. Ensuring students have a balanced programme with a variety of approaches may provide them with the required time to get used to the new approach, while maintaining a positive attitude towards new ways of learning.

Students’ Perspectives of Student Practice with Associated Recommendations

Reviewability

Generally, students were positive about the approach “I think I probably went a bit better for me doing the flipped instead of the traditional approach. Personally for me I like the dynamics need more tutorial/ lecture time, like engaging and asking questions about things I got stuck on. So that really helped me (Student N)”. One major advantage indicated by the students was the ability to view and re-engage with course content until satisfactory comprehension was reached, “I really enjoyed it coz I was able to pause it if I didn’t know something, pause it, google it, pause it, do something else, come back to it and it didn’t feel like you had to stay there the whole time” (Student I).

Independence

Most students appreciated that the lectures were closely followed by workshops and indicated that the approach meant that they were able to work more independently than in the traditional setting and thus gained a sense of empowerment:

> The flipped classroom is very self-directed learning. You have to sit down at home, you have to watch the lecture, you have to take notes by yourself, there is no one telling you that you have to be there in class, you can do whatever you want, you don’t have to go to the tutorial, you go there if you want help, if you want to push yourself and you want to learn more…but I think I really benefitted from it in the end. I really enjoyed the style and gained a lot more

> from, you get the materials beforehand because I think it gave me time to process it, digest it, to understand what I was looking at before I actually went in a did it (Student M).

A majority of the students liked the self-paced nature of the course, however a few felt that this disadvantaged them. A number of students noted the time commitment needed for viewing then reviewing lecture material.; “So it forces me to invest more time than I want to, than I can” (Student A). Two students noted that they believed the approach failed to prepare them for the schedules expected as professionals not always have the flexibility to prepare at their own pace before they solve real-life problems, “For quite a lot of jobs that you’re going to get coming out of a degree like this, you don’t wake up whenever you want and go to work” (student J). Nearly all students recognised the need for self-responsibility and discipline when engaging in a flipped classroom. “It takes a lot of self-control” (Student C). While some students thought this was advantageous, others recognised their own lack of self-disciple or maturity to cope with the approach meant that they were not as successful as they had hoped. A few students indicated that the flipped classroom approach might be more suitable for more self-disciplined students. “I wouldn’t have been able to do it when I was 18. There wouldn’t have been a chance” (Student P).

These findings further indicate the importance of students’ preparedness for the flipped classroom. Students in this study recognised the considerable difference to other approaches, and the need to adapt. In addition to the recommendation described earlier with regards to the lecturer’s role in preparing students for flipped learning, students themselves need to commit to taking on board strategies to self-direct and take ownership of their learning.

Time Management

Students recognised the importance of time management in the success in the flipped approach. Many students found that the on-line lectures took too long to watch and that the flipped approach generally took considerably more time than the traditional approach. “At some point I was struggling to keep up with watching the videos...also a bad thing because you spent a lot more time going over it”, (Student L). A number of students mentioned the need to engage in the prescribed course material at the appropriate times. “The moment you missed one and you go to the tutorial and have no idea what’s going on and then you kind of not waste that tutorial but you can’t fully engage in it so you have to re-watch it that night to catch-up” (Student O). Another felt that the increased investment in time was not reflected in improved grades. Some students indicated that they could have been better prepared for the flipped classroom approach, as it was difficult for them to learn in a non-traditional way.

These findings suggest that to succeed in the flipped classroom students must develop time management strategies and be self-disciplined to ensure lectures are viewed and materials engaged with in a timely manner. They also need to consider their preferred learning style, strategies that best suit their needs and where and how they can get assistance if required.

Working Collaboratively

The fourth factor in the student behaviour category was the collaborative nature of learning especially in the workshops. The majority of participants liked the collaborative nature of the workshops and enjoyed the resulting group dynamics. Most appreciated the small size of the classes and increased lecturer interaction compared to traditional classes.

> I definitely feel that working with a partner or small group really helped. As soon as I hit a road block or something that I didn't understand, I could bounce ideas off [student name] and he could do the same for me (Student D).

Two students indicated that they felt a responsibility to the group and made sure they were prepared to contribute at workshops. One student mentioned watching the on-line material with a classmate. They paused the video to clarify and discuss conceptual barriers,

> I was doing it with a very good friend of mine. We spent a lot of time we'd watch them together and we'd hit a problem and we'd both work through what [the lecturer] was trying to get towards, and the next day we'd be very confident in what we'd got (Student D).

Another student, while watching the material individually discussed and debated lecture material with a flat-mate also in the course. Socio-cultural conflict theory states that coming up against ideas differing to one's own enhance cognitive development when learners are open to change (Doise & Mugny, 1984). This was clear4ly demonstrated by a number of the students in this study.

Discussion and Recommendations

This study supports other studies presented in the literature on student perspectives of the flipped classroom in relation to students' behavioural factors (Hanson, 2016; Nguyen et al., 2015) and lecturer behavioural factors (Blair et al., 2016). This study has also identified a number of recommendations to improve the pedagogical approaches to the flipped learning with the aim of assisting tertiary academics from fields other than education in preparing their course materials, their students and themselves for the flipped classroom approach to learning.

One rationale for adoption of flipped classrooms in tertiary settings is the need to move to student-centred, problem-based learning, thus aligning with Vygotsky's (1978) sociocultural theory. Comber and Brady-Van den Bos (2018) found that student-lecturer relationships impacted on students' views of the flipped classroom approach. The positive approach of the lecturer in this study and his availability in workshops impacted on the students; views of the approach. When using the approach students gained immediate feedback in the workshops.

Quality materials facilitate a deep understanding given their problem solving and collaborative approach (Choi, 2013; Maykut & Morehouse, 1994; Serdyukov, 2015). Like those in Nguyen et al's (2015) study students in this study indicated that although the flipped approach took more of their time, the reviewability of the materials and the collaborative nature of the workshops enabled a deeper understanding course material, however it supports Nguyen's findings related to quality of materials and these participants became were frustrated with a number of errors in the on-line materials.

Working collaboratively often involves coming up with differing views and supports sociocultural conflict theory (Doise & Mugny, 1984) that all learners' cognitive development, regardless of proficiency is benefitted by understanding alternative views and working with peers. Debate, argument and or disagreement assists students' cognitive development, if participants are open to change and new ideas (Doise & Mugny, 1984; Fox-Turnbull, 2016). Intercognitive conversation also plays an important role in the collaborative learning process. This type of conversation is one within which all participants gain new understandings through engagement in reflective dialogue. When participants are learning in, and about, a common context and engaged in constructive dialogue they assist each other while advancing their own knowledge (Fox-Turnbull, 2008). A number of students in this study mentioned the value of collaborative work when engaging in the on-line materials and with the workshop material. This aligns Mayer's (2002) study that suggested increased value of face-to-face interaction both with the lecturer and peers, and supports apprenticeship of thinking theory (Bishop & Verleger, 2013; Doise & Mugny, 1984; Lavelle et al., 2013). It also concurs with Serdyukov's (2015) ideas about the importance of collaboration and communication in the learning process.

Another advantage of the flipped approach, for students in this study and for the participants of a number of other studies (Blair et al., 2016; Johnson & Renner, 2012; Lavelle et al., 2013) was that they could adjust the course content delivery rate to their preference and review it at their own discretion. These findings also support the theory of the success and importance of student-centred learning (Vygotsky, 1978). Some students in this study, however felt that the flipped approach took more of their time and indicated that undertaking too many flipped approach courses at one time could be problematic. Students in the study recommended only having one or two courses using the flipped per semester. Thus we suggest that when considering whether to implement the flipped approach, university faculties and staff consider the broader view of the total student experience. Students should be offered a balanced varied programme, using a range of delivery methods designed to best suit their needs.

Mason et al. (2013) cited time management as an issue with the flipped classroom approach. This was partially supported by the findings in this study. Students acknowledged that the course was time consuming overall, however they also indicated that this was not necessarily a negative aspect as they made efficient use of the time and hence were able to decrease the burden of exam study. Hanson (2016) suggests that students need to be well prepared for the flipped classroom approach to learning. The findings of this study supported this as students found the approach more time consuming and felt that they needed to demonstrate strong time-management skills to succeed with the approach. Students need to have an understanding of the pedagogical principles underpinning the approach and to have specific strategies modelled to them (Admiraal et al., 2017). This study also determines that students need to understand the philosophy and pedagogy underpinning the flipped approach. Issues that emerged in this study such as lack of time management, self-discipline and inability to work collaboratively also emerged in other studies (Johnson & Renner, 2012; Lavelle et al., 2013; Mayer, 2002). Specific skills to assist students' preparedness need to be presented and modelled to students by teaching specific strategies for engaging with the approach and to increase students' receptiveness to new educational strategies and decision making to increase engagement with peers and lecturers in the flipped classroom as this will impact student learning considerably (Admiraal et al., 2017).

The quality of the lecturer developed materials in this study had a considerable impact of students' perspectives of the flipped approach and supports similar findings by Blair et al. (2016). The video materials developed had several mathematical and formulaic errors that were very time consuming to correct. While students were understanding of the difficulty in fixing the errors in the videos some indicated that the errors shook their self-confidence and increased the time spent viewing on-line materials, however others saw the mistakes as an advantage as they were forced to think very deeply and critically about the materials and the differences between their ideas and that presented on the video. Thus, coming up against alternative views to their own (Doise & Mugny, 1984).
To assist lecturers in the preparation of eLearning materials for the flipped classroom approach the authors make a number of recommendations. These recommendations, summarised in Table 2. are based on those presented in the findings section of this paper further informed by pedagogical knowledge.

Table 2 Key Recommendations for using the Flipped Classroom Approach in Tertiary Teaching

Recommendations for Lecturers	**Recommendations for Students**
• Variety of Materials • High Quality of Materials • Workshop Materials Signalled in Advance • Positive Lecturer Approach	• Thorough Student Preparedness • Positive Student Attitude • Organized Time Management Skills • Understanding Communication and Collaboration Skills' Role in Learning

• Specific Preparation of Students to the Approach • Understanding Communication and Collaboration Skills' Role in Learning	

As stated previously the students in this study frequently mentioned the value of the collaborative nature of the workshops, although they did not directly recommend specific collaborative strategies as a part of the flipped classroom approach. Collaboration and communication are vital components in the teaching and learning process (Clarke, 2014; Fox-Turnbull, 2016; Serdyukov, 2015). This justifies the additional final bullet point in each column in Table 2. Lecturers must believe in and model strong communication and collaborative skills to assist their students in developing their own understanding of the place and role communication and collaboration plays in learning.

Conclusion

This study aimed to investigate students' perceptions of a flipped classroom approach to learning dynamics in a Bachelor of Engineering programme in a New Zealand university. It found that students were mostly positive about the approach, which in part had to do with the process of the flipped classroom, but also to do with the approach of the lecturer. Students' perceptions of the flipped approach were broken down into two main categories, the first of which is Perceptions of Lecturer Practice which included the approach and delivery style of the lecturer, the development and quality of the course materials, the implementation of the process and the extent which the students were prepared by the lecturer for the changed approach. The second category Perceptions of Students' Practice included their preparedness for the self-directed approach to learning, the ability or willingness to engage with course materials and peers and their ability to manage their time throughout the course.

Having established best practice within the flipped classroom we can now turn to it application for design and technology related subjects in secondary and tertiary situations. Because of the practical nature of technology related subjects, the need for specialist facilities (often in short supply) and specialist teachers the flipped classroom offers an opportunity to maximize the use of specialist facilities and people. Students engage with theoretical ideas through the recorded classes which they then apply in 'class' time with specialist facilities and teachers.

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Exploring the relation between students' research behaviours in project courses and open innovation

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Abstract

In this study, the similarities between the actions of design students in product design project courses and open innovation processes were examined through a survey conducted among the students. Studies on open innovation were evaluated together with up-to-date discussions about design and its role in innovation and business environment in general. Since design can take crucial roles in innovation and management, the comparison of design students' actions in product design courses with probable expectations in the work environment can provide information about if these project courses could act as a preparation for a professional career. The theoretical relation between innovation and design was discussed and was followed by examination of similarities between product design project courses and open innovation environments. Afterwards, a brief field study conducted with third and fourth grade product design students was analyzed to explore any resemblance between their research preferences during product design project courses and open innovation practices. Also, their awareness on the open innovation subject was sought to understand if the possible resemblance was a result of design education's nature. The results suggest that students' attitudes during product design project courses are in line with an open innovation concept to a degree, even though their awareness of the subject is low.

Key words

design, open innovation, design education, design thinking, design students

Introduction

Since much recent literature describes design as a facilitator of innovation, the relevance of design to current ideas concerning innovation may also be worth exploring. Open innovation is a concept that has received a great deal of attention in recent years that concerns tendencies in the gathering and sharing of knowledge in industry; therefore, the role of the designer in open innovation practices may also be considered.

The relation of design to innovation and managerial activities is frequently discussed in the literature (Verganti, 2009; Norman & Verganti, 2014; Lockwood, 2009; Cooper et. al, 2009; Johansson-Sköldberg et. al., 2013). Scholars maintain that design education has the potential to facilitate the use of designers' abilities in organisations and industry, and that therefore a more integrated understanding of design capabilities should become a part of design education (Buchanan, 2004; Boyarski, 1998; Owen, 1990). These studies are of two general types. One concerns the ways design supports innovation activities, and addresses design-driven innovation. The other concerns the use of design in managerial activities and addresses strategic problem-solving through design thinking. The literature suggests that designers, who possess skills and knowledge stemming from various disciplines, may act as supporters and managers of innovation activities in an organization (Buchanan, 2001).

To explore the role of design in innovation in a more holistic way, innovation models can be investigated. The models relevant to contemporary innovation activities may light up the current role of designers in innovation. Exploring the evolution of innovation processes suggests that recent innovation models support developing information networks and communication platforms to produce an environment that includes more participants (Rothwell, 1994). The development of information technologies plays a major role in this tendency, as they provide the platform and communication infrastructure for producing a knowledge database.

The principles and methods used to share and gather information in innovation activities have been frequently discussed. Studies have found that the innovation process tends to become more open when the aim is one of sharing information with outsiders and gathering information from external sources. These trends are in line with Rothwell's (1994) theories about future innovation trends and are currently studied within the area of open innovation (Acha, 2008). Open innovation is also linked with design practices; some of the studies that explore the relation between design and open innovation have found that designers can facilitate open innovation in the business environment (Acha, 2008; Christiansen et. al., 2013).

Because education facilitates the core capabilities of professionals, investigating design education may reveal the core competencies of designers. The methodologies and preferences of senior students have been said to resemble those of professionals; the basic behaviour of designers is shaped in the educational environment (Oscan & Dogan, 2013).

When design education is explored through student work, their product design projects and design research do represent the professional design process on a smaller scale. Buchanan (2001) states that clinical design research, a common type of research in design education, also plays a major role in professional design processes. Therefore, students' preferred methods may reflect models and tendencies in product design research and product development in general. Since design is regarded as a facilitator of innovation, an exploration of educational design projects may reveal whether recent innovation contexts have an effect on students' tendencies.

This study aims to identify similarities between design students' approach to research and open innovation, as well as their awareness of the subject of open innovation. The question of whether the core competences of designers facilitate open innovation is addressed by analyzing the role of designers in innovation processes through an alternative point of view. The results of this study can be used to enhance design education to develop students' capabilities in a way that is in keeping with recent trends in innovation and management.

Open innovation and its connection with design education

The literature suggests that innovation processes have evolved from closed models to more open practices (Rothwell, 1994). In this section, models for the evolution of innovation are examined with the aim of identifying theoretical links to the core competences of designers.

Evolution of Innovation Models and Open Innovation

The study of the models for the evolution of innovation reveals an ongoing movement towards a more open research environment. This tendency can be concluded from models that study the generational evolution of innovation.

The first-generation innovation model is defined as a technology-push model, while the second generation is described as a market-pull model (Liyanage et. al., 2002). The third-generation model occurs as a feedback process between technology-push and market-pull perspectives, balancing them within a portfolio management system that is in line with companies' strategies (Van der Duin et. al., 2006; Groen & Linton, 2010). The fourth- and fifth-generation models stress a more open approach for innovation. The fourth-generation model describes a product development process that runs in sync with every partner both inside and outside the company, forming a structure that has been described as a "rugby model" (Rothwell, 1994). The fifth-generation model is a more expanded version of the fourth, involving every possible partner, including customers (Dodgson et. al., 2008); this model makes use of developed communication platforms to broaden innovation networks (Rothwell, 1994).

The change to a more external-oriented innovation process is also recognized within the study of open innovation (West et. al., 2014). Chesbrough (2006) defines open innovation as "use of purposive inflows and outflows of knowledge" to support internal innovation and broaden the external use of innovation. The practice of open innovation uses aspects of closed innovation to balance information flow and the protection of core competencies. (Chesbrough & Euchner, 2011). Gassmann and Enkel (2004) state that open innovation is likely to occur when there is an increase in interface complexity, industry speed, and product modularity; they also note that requiring tacit and explicit knowledge and developing positive externalities favour open innovation. Chesbrough (2012) also stresses that employee mobility enhances open innovation.

The definition of open innovation and its ability to bring new insights to existing practices and concepts, such as supply chain management, has been questioned within the literature (Trot & Hartmann, 2009). In a more recent work, Chesbrough (2012) clarifies that, while open innovation opposes closed models, it does not include every open model, such as open source. One of the main distinctions between open source and open innovation is said to be that open innovation maintains the protection and trading of intellectual property. (Chesbrough, 2012). Sharing unused innovation can be regarded as another aspect of open innovation that differs from former practices and theories (Chesbrough, 2004). Although there is no clear-cut definition of open innovation, and development of its theories is still needed, defining and setting boundaries to open the practices of companies has been described as generally beneficial (Huizingh, 2011).

Enkel et. al. (2009) observe that studies discuss three types of open innovation processes: the outside-in process, the inside-out process, and the coupled process. The outside-in process refers to the broadening of a company's sources through external knowledge integration, while the inside-out process has to do with bringing ideas to the market to be developed by other parties (Enkel et. al, 2009). Dahlander and Gann (2010) describe the pecuniary dimension as another aspect of open innovation; the outside-in and inside-out processes may both involve selling or revealing information. Finally, the coupled process defines a co-creation produced within strategic networks by various partners (Gassmann & Enkel, 2004); this is similar to the fifth-generation innovation process described by Rothwell (1994).

The literature reveals that the core difference between the innovation models of the past and open innovation is that the borders and dynamics of research are not pre-defined in open innovation practices (Chesbrough, 2004). Firms can announce that their R&D gaps will be filled by external sources (Chesbrough & Euchner, 2011). Companies can also share projects that have, in the short term, been evaluated as unsuccessful; this sharing allows them to monitor reactions to these projects in an effort to understand any potential that may have been missed (Chesbrough, 2004). Therefore, it can be said that open innovation benefits an organisation through the sharing of information in a collectively creative environment.

Open Innovation, Design and Design Education

Recent studies discuss design as an element supportive of innovation in general, and as an important aspect of open innovation in particular (Verganti, 2009; Acha, 2008). However, design as a source for innovation has generally been neglected in studies (Hobday et. al., 2011). Earlier studies defined innovation as a phenomenon that resulted from basic scientific research (Cooper & Press, 1995). It was understood that innovation grew from research, which formed the basis of a technology that evolved into a product (Trott, 2005). More recently, however, alternative approaches to the concept of innovation can be seen in the literature.

Verganti (2009) analyses the concept along the two axes of technology and meaning. The axis of technology refers to innovations created by technical improvements, which are similar to the developments that characterize the earlier definitions of innovation. The axis of meaning, however, includes changes that are created by design, which alters the product language and perception of the users (Verganti, 2009). Both axes also have radical and incremental dimensions; design-driven radical innovations result largely from research activities and interdisciplinary work, while incremental innovations result from user-centered design activities (Norman & Verganti, 2014).

The abilities of designers can enhance the open innovation process. One important dimension of open innovation is user involvement (Gassmann et. al., 2010). The ability of designers to work with customers is stressed in the studies that discuss the concept of design thinking. Design thinking combines designerly problem-solving with user-focused competition strategies. (Brown, 2008; Cooper & Junginger, 2009).

Cross (1990; 2001; 2004) asserts that the nature of problem solving in design involves coping with uncertainty. This idea is in line with the suggestion that design offers a means of addressing some aspects of 'wicked problems' that are hard to define (Rittel & Weber, 1973; Buchanan, 1992; Dorst, 2011). Cross (1990) also states that designers can (a) generate novel and unusual solutions, (b) work with incomplete data, (c) cope with uncertainty, and (d) apply their imagination to solve practical problems. The ability of designers to cope with complex problems may enhance a company's open innovation capability. Acha (2008) asserts that open innovation may occur as a result of a company's design activities, claiming that ". . . firms which actively undertake design activities for innovation and which use design to control the innovation process, are more likely to also pursue open strategies for innovation." This view is in line with the concept of design thinking, which defines design activity as a strategic problem-solving action that broadly enhance an organisation's practices (Hobday et. al, 2012).

Incorporating design in innovation activities may also enhance innovation through knowledge mobility. Radical design-driven innovation occurs more often in multidisciplinary environments and when designers work within a variety of areas (Dell'Era & Verganti, 2010). Chesbrough (2012) also points out that workforce mobility is more common in "artistic kinds of industries," suggesting that designers may be more willing to work in various fields. Therefore, designers may serve as facilitators of knowledge transfer both because of their innovation strategies and their tendency to work within different industries and companies.

Because design tends to support open innovation, design students, who cannot develop every aspect of their projects entirely alone, may be expected to practice the sharing techniques of this approach. However, whether their tendency to use open systems derives from their working environment, or whether it is a preference deriving from intentions compatible with the principles of open innovation, is unclear and merits further exploration.

Research

A research with senior design students was conducted with an aim to understand their preferences of data gathering and sharing, together with their awareness of open innovation. The research questions were as follows;

- What are students' tendencies for searching/gathering information in industrial design project courses?
- What are students' tendencies for sharing information in industrial design project courses?
- Are students' aware of open innovation concept?

A total of six questions were asked through a survey, including Likert-scale questions with non-mandatory open-ended questions. A survey was conducted with undergraduate students who were attending industrial product design programs of various universities in Istanbul. The questions aimed to uncover following issues;

- Frequently used research methods and their selection motives
- Students' behavior for sharing information with other students and their reasons
- Students' definition for an ideal research process in a professional work environment

Industrial design education entered Turkey's agenda with the American Marshall Aid Program in the early 60s. Even though the opening of the first program has been edited in Middle East Technical University (Asatekin, 2006), the education began in the early 1970s in Istanbul State Academy of Fine Arts (Küçükerman, 2006). When examined, it can be seen that at the beginning of the industrial design education in Turkey, contrary to world, Turkish industry did not see design as a requirement (Er, 1993, Özcan, 2009). In the '60s Turkey, industrial design education began with support from the modernist, developing and developmental circles, especially from the architectural and interior architectural academies (Celbiş, 2006). This situation has resulted in the adaptation of systems which are taken from other professions and disciplines in order that the industrial design cannot create its own language during the education process (Günal Ertaş, 2011; Bayazıt, 2006).

As a result of these adaptations, design education in Turkey has evolved around two diverse disciplines which can be summarized as LYS (undergraduate placement examination) and aptitude examinations. The two major universities that conducted aptitude tests are Marmara University and Mimar Sinan Fine Arts University; while others mainly accept their students through LYS examination. Through this examination, eligibility for solving problems on topics such as math's and physics are evaluated. However, in aptitude tests students are asked to make drawings that answer the requirements provided by the judges.

Industrial design education, influenced by the origins of architecture and interior architecture education, has found its identity nowadays. Design education, especially in project courses, encourages students' own design ideas and identities by excluding trends, styles and movements (Balcıoğlu, 2009). There is a transition from a design education concept where the design student is tested in terms of technical and aesthetics, to a process in which many elements are tested and questioned during the development process of the design idea.

Within this study, students from two differing disciplines are included as all of them are employed as "industrial product designers" following their graduation. Therefore, to portray a more holistic "designer" profile at the beginning, no separations were made between students. However, it should be noted that students may have differing preferences on gathering of information. There are various types of problem-solving approaches in design mentioned in the literature (Dorst, 2003), which maybe create different profiles among students related to their educational background (Resnick, 1999).

Within the research, surveys were conducted with 50 students from a total study population of 160 from 5 different universities in Turkey. Descriptive univariate analysis was conducted with an intention to form insights together with open ended questions (Cooper & Weekes, 1983). The questionnaire was answered between November 2016 and December 2016, and the data was analyzed with SPSS and Excel according to ±4.62 % sampling error with a confidence level of 95 % $Z = 1.96$ $p = q = 0{,}5$ (Cohen, 1988; Soper, 2016; Westland, 2010). All of the students were senior students (either third or fourth grade) of product design undergraduate programs. Since senior students have more experience in a design process, purposive sampling was used (Robson, 2002). The questionnaire was mostly filled by researchers during a short interview with students; other students completed surveys by themselves, following the instructions provided from researchers. The surveys were filled anonymously, no personal information was required from students.

The survey included 4 Likert-type questions with independent sub-sections, which were evaluated with frequency distribution (Likert, 1932; Gray, 2013). Likert type questions were formed to explore the students' tendencies for using different mediums in various scenarios that could be involved in a research process. Each Likert type question was followed by a non-mandatory open-ended question to explore the motives behind the students' tendencies. At the end of the questionnaire, 2 non-mandatory open-ended questions were also added to study students' awareness on open innovation concept and how they define an ideal design research process.

The open-ended questions were thematically coded (Braun & Clarke, 2006). The most frequent codes were identified and they were evaluated according to their nature, such as supporters and hindrances of students' attitudes.

The questionnaire was evaluated in three parts. The first part explored how students search for relevant data during their projects. It is usual for a student to search for a data from sources outside, as they do not have the necessary know-how or research sources themselves. Also, the data that is provided at universities can be somewhat limited, as product design covers various types of artifacts that are produced in an industrial environment. Therefore it was necessary to conduct interviews with students to understand their preferences, and motives related to them. Their motives about why they choose a certain medium can provide clues on their awareness or willingness on open innovation. These tendencies could be identified by tendencies on both gathering and sharing of the data. Therefore, in the second part, their tendencies about sharing information were studied. It is not mandatory for a student to share information with others; therefore the general willingness and motives may hint at their overall behavior. Finally, their awareness about the research processes in general and open innovation was sought. The clarification of their knowledge on the subject can address if their motivation and actions are affected by their theoretical knowledge and education, or if they are originated from their routine actions.

Students' Tendencies on Gathering Information

The first two questions in the survey explored students' tendencies on gathering information. Therefore, their preferences of media for searching data and asking questions were studied.

The first question of the questionnaire asked students how often they used the listed media for their research purposes. The question was followed by an open-ended question about the general reasons for their choices. The 5 media, frequencies and mean values for those media are listed in the Table 1 below.

Table 1. The medium students prefer for searching data

Medium	1	2	3	4	5	Mean
Search engines and general portals (Google, shopping websites, consumer forums, etc.)	0	0	0	26%	74%	4,74
Design / engineering oriented portals (Coroflot, Designboom, etc.)	4%	12%	22%	26%	36%	3,74
Project-oriented student groups (Facebook, WhatsApp, etc.)	20%	26%	36%	10%	8 %	2,54
Other students that work on similar subject	2%	32%	26%	26%	14%	3,18
Specialists /experts	4%	19%	33 %	31%	13%	3,12

The reasons for students' choices were thematically coded. Among the 50 students that answered this question, 29 mentioned "ease of access" as a motive for their tendency. "Access to trustworthy information and experienced people" were mentioned as a reason 8 times, "gathering alternative opinions" were mentioned as a reason 6 times and "gathering alternative opinions" were mentioned as a reason 5 times. "Catching a new idea" and "information exchange" motives were mentioned once each.

Some of the expressions from students can be seen below.

"Because I can easily reach them" (Ease of access)

"Because they have experience" (Access to trustworthy information and experienced people)

It can be sensed that students' motives were reflected in the choices they declared. As the most accessible media, "Search engines and general portals" had the highest mean value. "Design / engineering-oriented portals" had the second highest mean value with 3,74 as it can be referred an easy way of reaching to experienced people on the subject. "Other students that work on similar subject" and "specialists/experts" both have mean values above average, as they are accessible and trustworthy, respectively.

The second question about students' tendencies for gathering data asked the participants how often they posted or asked questions in the listed media. The Likert-type question was followed by a non-mandatory open ended question which asked the reasons for their preferences. The media, frequencies and mean values are listed in Table 2 below.

Table 2. The medium students prefer for asking questions

Medium	*1*	*2*	*3*	*4*	*5*	*Mean*
Search engines and general portals (Yahoo Answers, forums, etc.)	*28%*	*26%*	*22%*	*16%*	*8%*	*2,56*
Design / engineering oriented portals' forums (Coroflot, Designboom, etc.)	*42%*	*30%*	*6%*	*14%*	*8%*	*2,20*
Project-oriented student groups (Facebook, WhatsApp, etc.)	*18%*	*18%*	*36%*	*20%*	*8%*	*2,86*
Other students that work on similar subject	*0*	*14%*	*32%*	*30%*	*24%*	*3,68*
Specialists /experts	*6%*	*20%*	*20%*	*24%*	*30%*	*3,40*

When the motives that students declared for their tendencies were coded, "ease of access" was again the most mentioned reason, as 24 students among 50 mentioned it. "Access to trustworthy information and experienced people" rated the second most mentioned reason as it was declared 16 times. "Gathering alternative opinions" was mentioned 7 times, and "information exchange" was mentioned once. Hindrances were also mentioned in these questions as "confidentiality" and "data pollution" were mentioned once each.

Some of the answers provided by students are listed below.

"Ease of access and potential to lead to other sources" (Ease of access)

"To reach experts of the subject" (Access to trustworthy information and experienced people)

It can be claimed that students tend to use media that are easy to reach and trustworthy. Students ask questions to the other students that currently work or previously worked on similar subject with more than average frequency. The "other students that work on similar subject" has the highest mean value with 3,68; while "specialists/experts" have a mean value of 3,40 which reflects students' need for reliable data. All of the other media had a mean value below average.

Students' Tendencies on Sharing Information

The third and fourth questions in the questionnaire aimed to clarify students' general tendencies about sharing information. Since their tendencies may differ according to relevance of the data to their projects, their tendencies about information that are directly related to their projects were asked, to be followed by their tendencies about sharing data that are not directly related to their projects.

The third question of the questionnaire asked students how often they shared information (technology, idea, etc.) that is significant for their current projects on the listed media. Again, the question was followed by an open-ended question about the general reasons for their choices. The 4 media, their frequencies and mean values are listed in the Table 3 below.

When the reasons that were mentioned by students were coded for this question, it was seen that "information exchange" and "gathering alternative opinions" were mentioned both 25 times out of 50 students. Two students declared "sincerity" was a reason for their choices, while "ease of access" and "access to trustworthy information and experienced people" were mentioned twice. Three different hindrances were mentioned in this question, as "not being social" was mentioned 8 times while "confidentiality" was mentioned 6 times and "inefficient communication" were mentioned 4 times. "Dilatoriness" was also mentioned once.

Table 3. The medium students prefer for sharing information related to ongoing projects

Medium	1	2	3	4	5	Mean
General portals (Pinterest, personal blog, Facebook timeline, Twitter etc.)	52%	22%	8%	16%	2%	2,00
Design / engineering oriented portals (Coroflot, Behance, etc.)	72%	14%	8%	0	6%	1,54
Project-oriented student groups (Facebook, WhatsApp, etc.)	38%	20%	26%	4%	12%	2,38
Other students that work on similar subject	22%	12%	12%	28%	26%	3,10

Students mostly mention "information exchange" in the context of being helpful to others. Some of the examples for the answers can be seen below.

"To provide benefits to other students" (Information exchange)

"To get information that is beneficial to my project" (Information exchange)

"To get feedback" (Gathering alternative opinions)

Only "other students that work on similar subject" scored above average with a mean value of 3,10. "Project-oriented student groups" has also a mean value of 2,38; while others scored below 2.

The fourth question of the survey asked students how often they shared data (technology, idea, etc.) that is not significant for their current educational projects on the listed media. The following open-ended question invited them to declare reasons for their preferences. Again, the 4 media, their frequencies and mean values are listed in the Table 4, which can be seen below.

Table 4. The medium students prefer for sharing information that is not related to ongoing projects

Medium	1	2	3	4	5	Mean
General portals (Pinterest, personal blog, Facebook timeline, Twitter etc.)	36%	28%	18%	10%	8%	2,30
Design / engineering oriented portals (Coroflot, Behance, etc.)	64%	18%	8%	2%	8%	1,72
Project-oriented student groups (Facebook, Whatsapp, etc.)	34%	10%	28%	20%	8%	2,58
Other students that work on similar subject	18%	20%	20 %	24%	18%	2,94

The most mentioned reason in this question was "information exchange" as it was mentioned 31 times out of 50. "Sincerity" was mentioned 7 times, while "Gathering alternative opinions" was told 4 times and "access to trustworthy information and experienced people" was mentioned once. "Not being social" was mentioned 4 times as a hindrance, while "inefficient communication", "no contribution" and "dilatoriness" were mentioned once.

Some of the answers provided by students can be seen below.

"To share information with the people that are interested" (Information exchange)

"…interdependence with friends" (Sincerity)

Again, "other students that work on similar subjects" was the only option that was rated above average with a mean value of 2,94. "Project-oriented student groups" had a mean value of 2,58, which was relatively closer to average. These preferences can be linked with students' motives to exchange information with the people that are relatively sincere to them.

Students' Awareness on Open Innovation

The last two questions aimed to identify students' awareness of modern innovation concepts, and open innovation, specifically.

In the fifth open-ended question, students were asked to describe an ideal research process in a professional working environment. The aim was to code data that referred to open innovation.

Among the 48 students that replied this question, 31 mentioned "interaction with customers", while 16 mentioned "talking with experts". None of the students mentioned any medium such as patent databases, cooperation with other firms or open access data use.

As the final question, students were asked if they had any idea about open innovation concept. From a total of 45 students that answered this question, 39 declared that they did not have an idea about the context. Three students correctly described open innovation, while two mentioned open source development and one mentioned both open source concept and open design concepts together.

Discussion

In evaluating the results of the survey, it can be seen that student behavior is to a degree in line with the principles of open innovation. However, they have only a slight awareness of the subject, and they do not think that they should continue to access and share information in an open way when they have entered professional practice.

The behavior of students seems to change as they are required to give more information about the project they are working on. When they search for general information, they do not have to reveal anything about their projects, so they use the media more frequently. As they provide more specific information about their projects, the frequency of their media use seems to lessen. This tendency can be seen in their preferences for data collection; when they are required to ask for specific information that may provide clues about their project, they tend to talk with the students they are close to, while they talk with experts, relative outsiders, during the project development process. The same preference is also seen in how the students share data; when they are sharing information that is not directly linked with their projects, they use media more frequently. "Confidentiality" is mentioned as a hindrance when they are sharing information that may provide a hint about their projects. The same tendency can also be seen in their research methods.

Some of the reasons they mention, such as “ease of access” and “access to trustworthy information and experienced people,” can be understood as issues that lead students toward a more open process. As students cannot build every detail of their projects themselves, they rely heavily on outside data. Current communication technologies, easy to access and up-to-date, may also direct students to more open information sharing.

Conclusions

In this study, applications of the students in product design programs were studied regarding open innovation. The students’ awareness of open innovation was also explored to see if their tendencies were affected by this context. It can be seen that although students lack awareness on the subject of open innovation, their research activities are in line with the context. Encouraging students about the application of open innovation might be helpful in maximizing their potential in innovation processes, preventing them from developing ineffective understandings about product development processes.

The results suggest that students seem to behave in a way that is compatible with the practices of open innovation. They search and share data in an open way; however, they prefer not to provide details that will reveal the essential qualities of their projects. This preference is in keeping with the core principle of open innovation concerning the protection of intellectual property (Chesbrough, 2012). Companies do not use the open innovation model in every aspect of their research process; instead, they use a mixture of open and closed models to find a balance between gathering useful data and not damaging the advantages obtained from their core competencies (Chesbrough, 2004; Chesbrough & Euchner, 2011).

Even though their behavior may be consistent with open innovation practices, students do not seem to have a sense of the subject. They conceive of product development research as a closed process; they do not describe collaboration with outside sources as a necessary or beneficial part of research and development. As they do not mention implementing some of the research techniques they use during their projects, it could be that most of their preferences are determined by their ease of access and the credibility of the mediums. Lacking knowledge of the subject may lead them to waste of their potential as participants in open innovation. Because students feel that closed processes are more preferable in professional environments, their research practices may be better directed to avoid a strong propensity towards these outdated methods.

To sum up, the way design students behave in their project design courses is consistent with the core concepts of open innovation. However, their actions should be supported by theoretical knowledge about the subject to create awareness about their potential as professionals in a modern business environment. Otherwise, their prejudices about the sharing of knowledge in the product development process may harm their roles in business and management, preventing them from being employed as open innovation facilitators based on their tendency to work between fields.

Additional studies could further explore students' ideal design project research scenarios. Students could be interviewed about what an ideal research process would be for their practice. A workshop could then be modelled according to these results to provide the media mentioned by students along with others; in this environment, it would be possible to see whether they indeed favour closed research scenarios or whether they end up using the methods of open innovation. The same workshop could be conducted with students who are already informed about the open innovation to see if their lack of knowledge has an effect on their actions.

Another point that could be considered would be the differences between student groups from two different disciplines. Students from diverse educational backgrounds could be expected to differ in their practices, especially in terms of gathering research.

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Design Divergence Using the Morphological Chart

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Abstract

This paper investigates the effectiveness of the morphological chart method in design divergence. The literature presents the morphological chart as an engineering design method that does not particularly aim novelty, but instead gathers possible means for fulfilling the independently decomposed sub-functions of a product. On the other hand, implementations of this method in design education has shown that this method offers the possibility of design exploration for groups of interrelated sub-functions. Accordingly, this widens the solution space and encourages designers to think on the consequences of their design decisions while generating ideas, hence allowing situated design divergence to take place. The paper presents the findings of a review carried out on twelve morphological charts completed in groups, containing a total of 686 sub-solution sketches made for a pool of 21 sub-functions. The charts were reviewed as a whole in terms of group performance in idea generation for a decomposed design problem. Then the sub-solution ideas were grouped according to sub-functions and were reviewed in terms of idea content. It was seen that a background preparation with product trials, 3D exploration of product configuration, and experience in using the morphological chart method, affected the number of cells that the participants completed. Besides, several factors were found to influence the ways in which participants filled in the morphological charts. The reviews revealed eleven factors affecting design divergence using the morphological chart method, grouping under the headings of: preparations, group dynamics, boundaries of sub-functions, and interrelations of product components. In addition, thirteen strategies were identified that participants followed for idea generation using the morphological chart method, grouping under the headings of: beginning idea generation, ensuring effective idea generation, exploring ideas, diversifying ideas and representing ideas.

Key words

morphological chart method; design divergence; idea generation; sub-functions; sub-solutions; visual content analysis

1. Introduction

A main objective in design education is supporting prospective designers in developing and mastering skills in carrying out design exploration. The usage of generative methods is an important resource in simulating design situations allowing this process to take place (Daalhuizen, Person and Gattol, 2014; Curry, 2014; Cash, Elias, Dekoninck and Culley, 2012). This paper presents the findings of a study that reviews the outcomes of the implementation of such a method.

Generating alternative design solutions for products with multiple components can present difficulties particularly when components are expected to fulfil coordinated sub-functions within a technical-physical system. Closely related sub-functions of a product may lead to tight boundaries of physical components (e.g. interrelated components with predefined parameters), leaving limited space for design interventions. For such design problems, design exploration may remain limited and variety in idea generation may not be achieved. In this case, methods that ensure design divergence must be chosen. The literature offers many idea generation methods used for widening the solution space for engineering and product design, the morphological chart method being one of them.

Widening of the solution space is about determining the boundaries within which design exploration will take place, such that several and diverse possibilities can be considered. This involves design divergence, which is about generating an extensive range of alternative ideas that will contribute to this exploration. The more informed this process, the more appropriately the boundaries of the solution space will be set, and better this exploration will be grounded. An in-depth analysis of the problem is thus important in preparing for this exploration, as i) it contributes to the designer's understanding of the problem context and components, ii) supports the reasoning behind idea generation, and iii) provides the criteria based on which the outcomes of the design exploration will be evaluated and processed.

This paper presents the findings of a study on the outcomes of the morphological chart method implemented for a short-term educational project on drip filter coffee makers. The project was repeated four years in a row, for a graduate course on design methods, with different sets of students participating in the project each time. The project followed a design process that began with an in-depth analysis of the design problem (drip filter coffee makers), followed by idea generation using the morphological chart method. The outcomes of the method were A1 size charts containing many table cells filled in with freehand sketches. Fundamentally, the method was found to be effective in achieving design divergence. Concentrating on the content of twelve morphological charts prepared by twelve participant groups for drip filter coffee maker components, collected throughout the four years, this paper examines the performances of participants in design divergence in order to identify the factors that contributed to the effective implementation of the method. The charts contained a total of 686 freehand sketches for sub-solutions. A visual content analysis of this data was carried out to reveal the ways in which participants extended and explored the solution space. The research questions were:

- What are the factors affecting participants' performances in design divergence using the morphological chart method?
- What are the strategies that participants followed for idea generation using the morphological chart method?

Within this framework, the paper begins with a literature review on the morphological chart method, its aims and outcomes, the significance of design divergence for idea generation, and the ways in which the method supports it. The paper then describes the study and data analysis procedure. The paper concludes with the presentation of the findings answering the above research questions, and a brief discussion on insights gained on design divergence for a fixed problem.

2. The Morphological Chart Method and Design Divergence

The morphological chart method is based on the General Morphological Analysis (GMA) method developed by Fritz Zwicky, for the investigation of non-quantifiable problem complexes (Ritchey, 2013; Ritchey, 2017). The method is used for breaking down a problem into sub-functions (problem decomposition), generating numerous sub-solutions for these (design divergence), and selecting and combining the suitable sub-solutions into alternative overall solutions (design convergence) (Cross, 2000; Magrab, Gupta, McClusky and Sandborn, 2010; Pahl and Beitz, 1996; Roozenburg and Eekels, 1995; Wright, 1998). This method is recommended for use particularly in idea development stages, where the solution space is extended in search of all possible means that can act as a solution for a sub-function; this includes a search for form, as the name (*morph-*) implies. Richardson, Summers and Mocko (2011) summarise the benefits of the morphological chart method as: enlarging the design space to be explored, generating novel concepts that would otherwise not be considered, and representing a wide range of concepts allowing the unexpected matching of components to be considered.

The morphological chart is a table that lists the sub-functions on the first column, and places numbers in the cells of the heading row to represent sub-solutions (generally around six) (Figure 1). The first step of the method is to determine the sub-functions expected from the final solution to fulfil, which can be done using various methods such as function analysis (Sapuan, 2005; Roozenburg and Eekels, 1995), brainstorming (Yang, 2009), determining product design specifications, and customer requirement analysis (Wright, 1998). It is expected to consider all possible means of fulfilling a sub-function when filling in the morphological chart (Wright, 1998) and this works best when the sub-functions are considered as independent of each other as possible (Cross, 2000; Roozenburg and Eekels, 1995). The sub-functions are expressed in the same level of generality and preferably in abstract terms rather than referring to physical components (Cross, 2000).

	Sub-solution 1	Sub-solution 2	Sub-solution 3	Sub-solution 4	Sub-solution 5	Sub-solution 6
Sub-function 1						
Sub-function 2						
Sub-function 3						
Sub-function 4						
Sub-function 5						
Sub-function 6						
Sub-function 7						
Sub-function 8						

Figure 1. A typical morphological chart representing eight sub-functions and six sub-solutions, yielding a total of 48 cells to be filled in with design ideas.

The next step is to fill in the rows for each sub-function with ideas for sub-solutions. These sub-solutions should offer means to achieve the sub-functions, and therefore represent physical components. Various strategies may be followed in filling in the charts. Hsiao and Huang (2002) apply several shape generation rules to diversify product types, following a certain logic, such as changing the shape of one part and keeping the rest the same, then changing the shape of two parts, and so on. In their experiments, Smith, Richardson, Summers and Mocko (2012) constructed morphological charts with tables in different sizes, variating the numbers for the sub-functions and sub-solutions (*means*). Their evaluations of engineering student performances showed that the final design solutions obtained from charts with a higher number of means and a lesser number of sub-functions gave better results in terms of task management and quality design concepts. Their findings emphasize the benefits of limiting functional decomposition, and rather allowing space for the conduct of idea generation for sub-solutions. As such, the literature recommends a comprehensive list of sub-functions that is not too long (Cross, 2000; Wright, 1998; Roozenburg and Eekels, 1995) and 8 to 12 items seem to be ideal.

The completed chart presents alternative sub-solutions from which to combine, yielding a large number of alternative solutions. This is presented in the literature as a weakness of the method, the disadvantages of which are cited as: difficulties in exploring the large number of concepts, not all combinations of components yielding feasible solutions; and lack of guidelines for determining those components that would be useful (Richardson et al, 2011; Smith et al., 2012). Therefore, the selection of sub-solutions to combine requires effective strategies for evaluating potential sub-solutions (Roozenburg and Eekels, 1995). To prevent the information overflow that this method can create, Lo, Tseng and Chu (2010) suggest using the quality function deployment method (QFD) in advance in order to transfer client requirements into design specifications and then into function modules, and also computer modelling the sub-solutions to be able to assess their feasibility as they are being generated. Mansor, Sapuan, Zainadur, Nuraini and Hambali (2014) suggest first using the theory of inventive problem-solving method (TRIZ) in order to generate solutions, then using the morphological chart as the idea refinement tool, to be able to generate relevant solution principles that are transferrable into specific design features. Van Boeijen, Daalhuizen, Zijlstra and Vander Schoor (2013) suggest grouping sub-functions and rank ordering them; sub-solutions are thus selected according to sub-function groups in order to facilitate the evaluation process. Magrab et al. (2010) suggest rank ordering sub-solutions per row. Pahl and Beitz (1996) suggest using compatibility matrices in order to assess the degree to which two sub-solutions match one another. Mansor et al. (2014) recommend the analytical hierarchy process (AHP) as the concept design selection tool.

The final combinations can be given diverse embodiments (Magrab et al., 2010). Consequently, this also requires effort in revising, interpreting and adapting the selected sub-solutions while synthesizing an overall design solution (Pahl and Beitz, 1996; Roozenburg and Eekels, 1995).

Lo et al. (2010) explain that morphological charts are frequently used for product variant design, the generation of new designs made by changing the parameters of certain features of existing design. Various sources specify that this method does not particularly aim novelty through creative concept generation, but as Cross (2000: 105) remarks, provides “variations on established themes”, and this is an important design activity also forming the basis for creativity that displays itself as the restructuring of prevailing components. Cross (2000) describes the morphological chart method as an opportunity for systematically restructuring components under various combinations and thus extending the solution space for design exploration. The solution space is extended in two aspects: from an analytic perspective by generating alternative sub-solutions for decomposed sub-problems; and from a synthetic perspective by generating alternative combinations of these sub-solutions into overall solutions. Referring to different stages of the design process, the designerly activities required for both tasks are a combination of *divergence* and *convergence*.

Divergence is the initiating phase of the design process where the design problem is broken down into parts for *analysis*. Analysis is about carrying out various activities such as research, technical inquiry and concept search towards extending the solution space for the sub-problems. This phase prepares for the phase of *transformation* where design synthesis takes place; which is followed by the phase of *convergence* where alternatives are evaluated for selection (Jones, 1980). Within this context, Hsiao and Chou (2004) consider the morphological chart as a technique employed in the transformation phase where the problem components are identified as product features, and creative solutions generated for these are combined into alternative designs. In brief, design divergence that the morphological chart method supports, takes place in the analysis phase of the design process, where the design problem is broken down into its components and numerous sub-solutions are generated for these, and then in the synthesis phase where the selected sub-solutions are brought together into alternative overall solutions. This paper is concerned with design divergence taking place in the analysis phase, as this is the stage where an intensive design exploration is required for situated idea generation.

3. The Study

A short-term project on drip filter coffee makers was carried out four years in a row for a graduate course on design methods. The design problem was the renewal of the typical drip filter coffee maker (DFCM from hereon) by making product modifications, and the same project brief was given in each of the four years. The drip filter coffee maker was chosen to be studied as a design problem for its interrelated structure of components. The design process followed was composed of the stages of a) problem analysis, b) idea generation, and c) development of the final design proposal. The problem analysis stage was planned for an in-depth exploration of the design problem, to build the necessary technical and functional background for a grounded design exploration. The implementation of the morphological chart method took place in the idea generation stage, and aimed for an extensive design exploration before moving on to the stage of final design proposal development. As a result, twelve morphological charts were collected over the four years.

The study described in this paper was carried out to investigate the role of the morphological chart method in supporting design divergence for a fixed design problem, and the factors that contributed to the effective implementation of the method. The focus of the study was the contents of the twelve morphological charts. The study involved a two-step review.

- The design process was reviewed for all four years, in order to determine the contribution of the preparations made, to the idea generation stage. The data for this comprised of the project brief and exercise briefs distributed in class to the participants, and the submissions that the participants made (collected digitally).
- Then, the morphological charts, prepared by groups of participants, were reviewed in terms of content and representation, in order to examine the participants' performances in effectively using the method, and identify their idea generation strategies. The data for this included the digital copies of twelve A1 size morphological charts filled in with 686 freehand sketches of ideas for DFCM components.
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3.1 The Participants

Four different sets of graduate students participated in the project in respective years; the total number of participants were 50 (Table 1). Forty-four had background in design-related fields (42 industrial designers, two interior architects). Six were from fields other than design (preschool education, mechanical engineering, industrial engineering, business administration). The participants worked in groups for the tasks carried out in each stage of the process; the final submissions of design proposals were made individually.

Table 1. The participants

Participants (Total: 50)	Female	Male	MSc	PhD	Design background	Non-design background	
2013	05	01	04	02	04	02	06
2014	09	08	11	06	15	02	17
2015	13	06	13	06	19	00	19
2016	03	05	05	03	06	02	08
TOTAL	30	20	33	17	44	06	50

3.2 The Design Process

The project was carried out in four course sessions, each being four hours once a week. The design process followed for the project was the same for all four years (Figure 2).

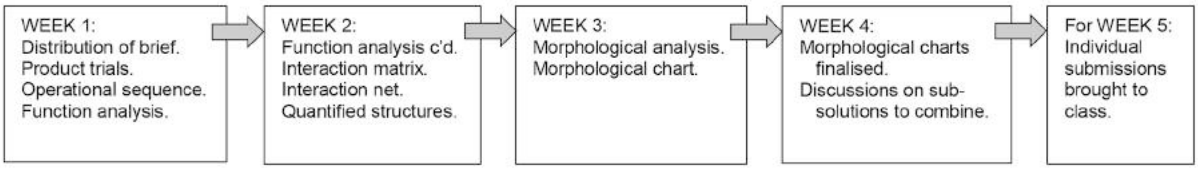

Figure 2. The time plan followed for the DFCM project design process.

i) Product Trials: The process began with trials of various product examples to understand how DFCMs operate. Participants prepared filter coffee for themselves using drip filter coffee makers brought to class. The number of the DFCMs ranged from five to seven per year (Table 2).

Table 2. The drip filter coffee makers used in the project

	Arçelik	Bosch Private Collection	Braun	Ciatronic	Goldfilter	Philips MyAroma	Touchme
							
2013	X		X	X	X	X	
2014	X	X	X	X	X	X	
2015	X	X	X	X	X	X	X
2016		X	X	X	X		X

ii) Operational Sequence: Determining Sequence of Product Operation: Based on product trials, participants prepared an operational sequence chart, which is a flow chart representing the way in which the product operates (Kirwan and Ainsworth, 2005). They were asked to identify the actions that initiate an operation, the chain of operations that follow during functioning, the actualization from the users' part during operations, the results of operational steps and how these impact new ones (Figure 3).

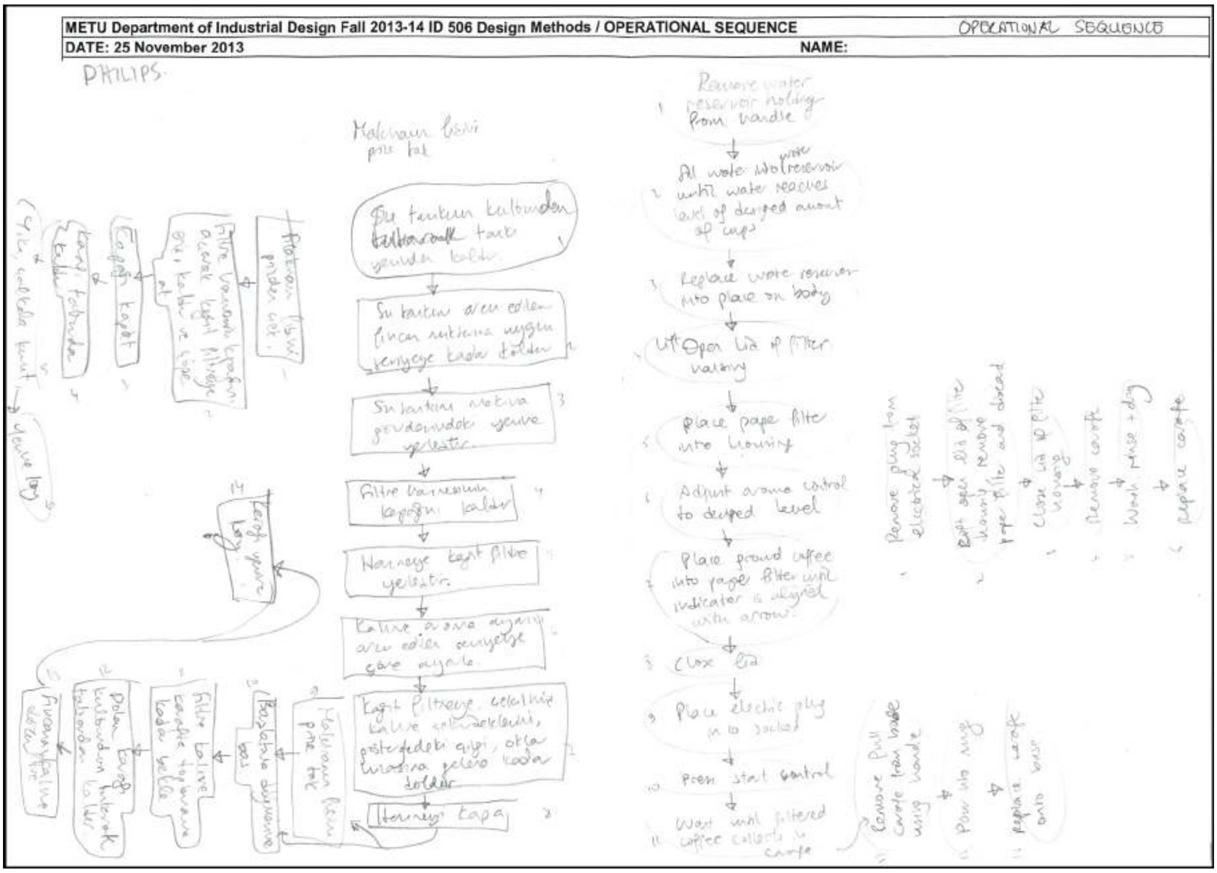

Figure 3. Operational Sequence Chart prepared for the Philips MyAroma DFCM (2013).

iii) Function Analysis: Determining Product Components and Sub-functions: Participants then made a function analysis (Roozenburg and Eekels, 1995; Cross, 2000), also known as problem decomposition (Wright, 1998) or function structure (Pahl and Beitz, 1996) (Figure 4). Function analysis considers the product to be a technical-physical system that is a means for transforming input into output (Wright, 1998; Cross, 2000). In the case of DFCMs, input is energy (electric) and matter (coffee and water), which are converted into output, that is filter coffee. Based on the function analysis of the products, the components were identified and their functions were described. Each component was given a letter and represented in a block diagram showing the interaction between means for sub-functions working together for realising the essential function (Wright, 1998; Cross, 2000), the function that the product must satisfy primarily (Srinivasan, Chakrabarti and Lindemann, 2012; Kitamura and Mizoguchi, 2010).

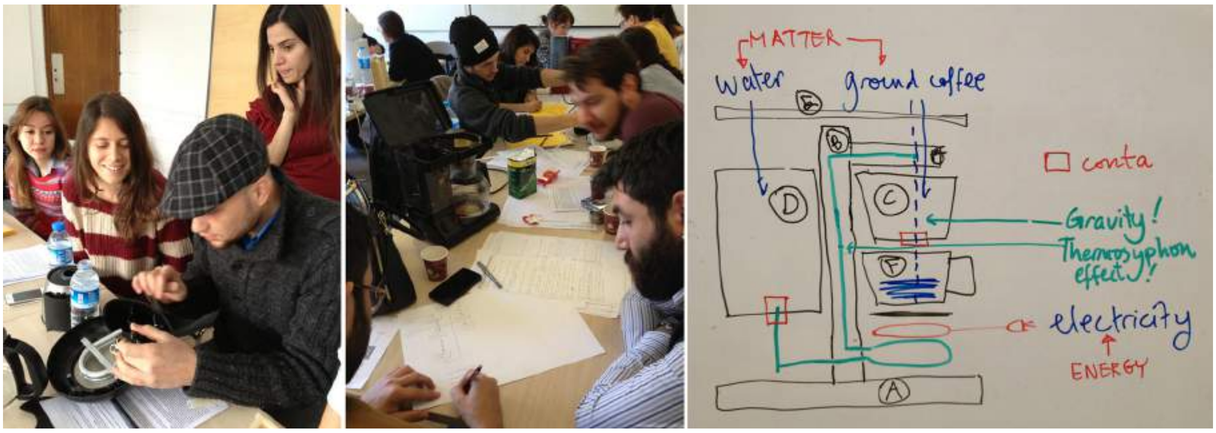

Figure 4. Left: Product disassembly during product trials (2013). Center: Function analysis during product trials (2014). Right: A diagram prepared collectively on white board based on function analysis (2015).

iv) Interaction Matrix and Net: Determining Functional Connections of Components: In the following stage, participants studied the functional relations among the components and their levels of connectedness using the interaction matrix (Jones, 1980). On the intersecting cells of the matrix the links between components were marked as either existing or non-existing depending on the type of connection. The interaction matrices were then converted into interaction nets (Jones, 1980) in the form of a diagram that displayed the direct links between components (Figure 5).

Figure 5. Left: Components and sub-components determined. Center: Interaction matrix and interaction net prepared for the components. Right: Three types of quantified structures identified for the DFCMs studied in class (2016).

This net allowed to determine among the seven DFCMs examined in class, three types of relative arrangements of components, which are variations on component configurations (Tjalve, 1979). The relative arrangement of a product is affected by the working principle based on which it operates (Pahl and Beitz, 1996). The working principles for the DFCM are *thermosyphoning* and *gravity*, around which the components are configured. When the water reservoir is placed in its position, the gasket underneath it opens, allowing water to run into a tube within the product base, placed underneath the hot plate. Between the hot plate and the water tube is positioned a heating coil. When switched on, the coil starts heating the hot plate and the water tube. The heated water rises upwards as a result of the thermosyphoning effect, and moves onto the filter shower head. The water thereon drips onto the ground coffee in the filter basket with the help of gravity, hence giving the product its name. Keeping these common working principles, the DFCMs varied in terms of component configurations.

v) Quantified Structure Analysis: Determining Structural Relations of Components: Participants next explored variations for the component configurations of the DFCM. They were asked to represent the relative arrangements of the DFCM components examined in class as simple diagrams of quantified structure and then generate alternative quantified structures in regard of the working principles (Figure 6, left). This type of diagram shows the configurations of product components and their dimensions (size, volume, distance) in correct proportions (Tjalve, 1979), and is used to search for alternative component configurations.

In the first two years, the exploration for quantified structures was carried out on paper, in two-dimensions (2D). In the following two years, the participants were asked to support their 2D exploration with three-dimensional (3D) representations of the components allowing component manipulation and spatial exploration (Figure 6).

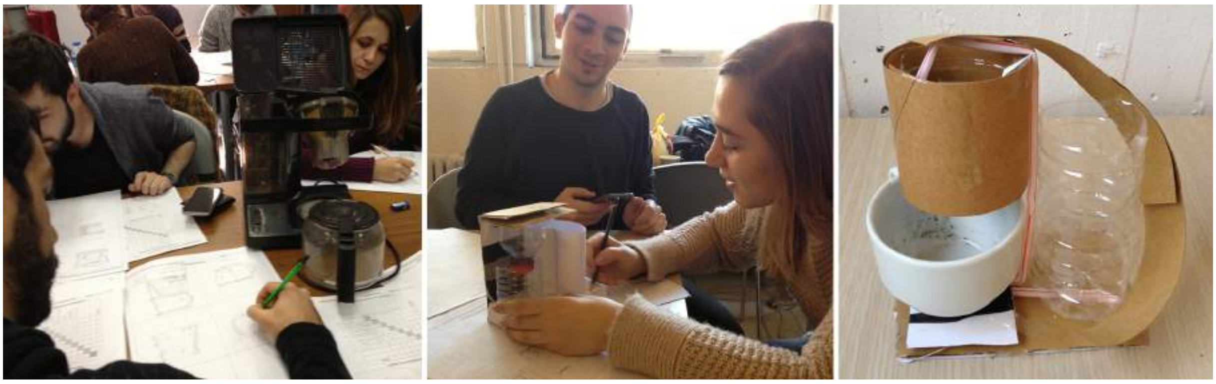

Figure 6. Left: Participants developing quantified structures in 2D (2015). Centre: Participants developing quantified structures in 3D (2016). Right: A 3D quantified structure (2016).

vi) Morphological Analysis: Determining Variations in Product Features: In the next stage, participants carried out a morphological analysis in groups to compare the DFCM components in terms of design features. Groups were handed out envelopes with shuffled images of the sub-components of the DFCMs studied in class. On charts that were distributed, they assembled and pasted these components according to the DFCMs that they belong to (per column) and the sub-functions that they fulfil (per row) (Figure 7, left). Groups then conducted discussions on the completed charts to compare the components and determine whether the designs differ in terms of *form*, *function*, *working principle* or *relative arrangement* (Figure 7, right).

Figure 7. Left: Groups sorting out their shuffled component images (2014). Right: Groups studying their completed charts (2015).

vii) Morphological Chart Method: Design Divergence for Product Sub-solutions: Subsequently, participants carried out idea generation for DFCM components using the morphological chart in groups. The sub-functions that the design solution must perform were determined altogether in a short brainstorming session. Groups itemised the sub-functions on the first column of their charts, and generated alternative sub-solutions that could perform the sub-functions on each row (Figure 8).

Figure 8. Left: Group of four working on their morphological chart (2016). Right: Group of four working on their morphological chart (2015).

The performances of the groups from the first two years of project conduct (2013, 2014) showed that, implementing the morphological chart method for the first time brought its limitations. It took two class sessions for these groups to fill in their charts, and most charts remained incomplete (Figure 9, left). Therefore, in the following two years (2015, 2016), to prepare for this project, a prior morphological chart exercise was conducted for a product of a less complicated component structure, for participants to familiarise with the mechanics of the method and amount of effort required. Thus, during the DFCM project, all participants from these two years had brief experience in using the method. The DFCM morphological charts of these years were prepared more rapidly, and almost all were complete (Figure 9, centre and right).

Figure 9. Left: DFCM Morphological chart with empty cells (2014, Gp-D). Center: DFCM Morphological chart filled in entirely (2015, Gp-H). Right: DFCM Morphological chart filled in almost entirely (2016, Gp-K).

viii) Final Design Proposals: When the task was completed, groups examined their charts and decided on the sub-solutions that would work well together in terms of function and attribute. Then, group members individually combined the sub-solutions that they chose from rows, to generate one alternative design proposal on A3 size sheets. These design proposals were the final submissions made for this project.

4. Analysis of the Data

The twelve morphological charts contained a total of 686 freehand sketches for sub-solutions, constituting the data for this study. This data was subjected to visual content analysis. Content analysis is a method that involves the decomposition of meaningful material (including visual and text) into identifiable units and their coding into a hierarchical classification that can then be processed (Krippendorf, 2004). From the classification can be determined patterns, revealing themes that help explain the material (Savin-Baden and Major, 2013). The contents of the DFCM morphological charts were reviewed using both quantitative and qualitative approaches. Two sets of A3 size copies were printed out from the digital copies of the original morphological charts. One set was used for an overall evaluation. The other set was used to cut out and group sub-solution rows for sub-functions. All sheets were displayed on the wall and analysed for visual clues. These clues were identified from the representations of sub-solutions, as drawing elements (Schenk, 2014; Suwa, Purcell and Gero, 1998; McGown, Green and Rodgers, 1998) and as independent units of design ideas (Goldschmidt, 2016; Sun, Xiang, Chai, Wang and Huang, 2014; Yilmaz and Seifert, 2011).

4.1 Quantitative Analysis

For a quantitative analysis, the number of cells on the charts, sub-functions treated, cells that offered sub-solutions for these sub-functions, and groups that addressed these sub-functions were identified and tabulated (Table 3). A total of 21 sub-functions were identified from the pool of sub-functions that groups determined for themselves, with the numbers of sub-functions explored in the charts ranging from 8 to 13 (Table 4). The sub-functions were thematically distributed into four categories, describing the groups of sub-functions that were functionally related. From among these, *sub-functions related to working principles* (water reservoir, filter housing, coffee strength adjustment, drip nozzle and carafe) were explored the most, with 269 cells dedicated to sub-solutions. These sub-functions are those supporting the essential function of the drip filter coffee maker, and include containing water (input), containing ground coffee (input) and containing filter coffee (output). This indicates an interest in the exploration of components that characterise the DFCM, and the central role that these components play in fulfilling its essential function.

The charts were then reviewed according to group performance. Group compositions were revised, revealing that five groups were mixed (A, B, C, K and L), with some participants from non-design backgrounds, and seven groups were formed of designers only (D, E, F, G, H, I and J). Five groups (A, B, C, D and E) from the first two years (2013, 2014), carried out a 2D quantified structure exploration only, and had no prior experience in using the morphological chart method. Seven groups (F, G, H, I, J, K and L) from the final two years (2015, 2016) carried out both 2D and 3D quantified structure explorations, and had experience in using the morphological chart method. In the first two years, the average number of filled-in cells per participant ranged from 7,2 to 11,34, whereas in the final two years, this number ranged from 15 to 24. It is seen that the average numbers of cells filled in per participant have risen in the final two years (Table 4). The groups F, G, H, I and J filled in all their cells, and Group K had only one cell empty out of 66. The charts with the lowest average numbers of full cells per participant were produced by groups A, B, C, E and L. Groups A, B, C and E were from the first two years, with participants using the method for the first time. Besides, groups A, B, C and L had members from non-design backgrounds. From this assessment, it was inferred that having carried out a 3D quantified structure exploration, experience in using the morphological chart method, and group composition, were among factors affecting group performance.

Table 3. The sub-functions explored

		Sub-function	No. of Groups	No. of Sub-solution Cells
Group 1: Sub-functions determining component configuration	1A	Structure	10	60
		Relative arrangement	2	12
	1B	Transfer of boiled water from reservoir to filter housing	3	16
		Boiling water	2	8
		Transferring water	8	38
				(134)
Group 2: Sub-functions related to working principles	2A	Water reservoir	12	67
	2B	Filter housing	9	50
		Adjustment of coffee strength	10	53
		Drip nozzle	7	34
	2C	Carafe	12	65
				(269)
Group 3: Sub-functions related to operating components	3A	On/off switch	9	42
	3B	Cable and cable storage	6	35
	3C	Hot plate	12	59
				(136)
Group 4: Features common to sub-functions	4A	Carafe handle	6	36
	4B	Carafe lid	2	12
		Water reservoir lid	2	12
		Filter housing lid	2	10
		Lid for overall DFCM	4	24
		Lid (mixed components)	1	6
	4C	Water level indicator	8	39
		Coffee amount indicator	1	8
				(147)
		TOTAL No. of CELLS		**686**

Table 4. Numerical information on the twelve morphological charts

	2D quantified structure exploration; No morphological chart experience.					**2D and 3D quantified structure exploration; With morphological chart experience.**						
	2013	2014				2015					2016	
	Gp-A	Gp-B	Gp-C	Gp-D	Gp-E	Gp-F	Gp-G	Gp-H	Gp-I	Gp-J	Gp-K	Gp-L
No. of group members (a)	6	4	5	4	4	4	4	4	3	4	4	4
No. of sub-functions (b)	13	8	9	9	10	12	11	12	12	10	11	11
No. of columns for sub-solutions (c)	7	6	6	6	6	6	6	6	6	6	6	6
Total no. of cells in chart (bxc) (d)	91	48	54	54	60	72	66	72	72	60	66	66
No. of filled-in cells (e)	68	36	36	44	41	72	66	72	72	60	65	54
No. of empty cells (d-e) (f)	23	12	18	10	19	0	0	0	0	0	1	12
Ave. no. of cells per participant (d/a) (g)	15,17	12	10,8	13,5	15	18	16,5	18	24	15	16,5	16,5
Ave. no. of filled-in cells per participant (e/a) (h)	11,34	9	7,2	11	10,25	18	16,5	18	24	15	16,25	13,5
Difference (g-h)	3,83	3	3,6	2,5	4,75	0	0	0	0	0	0,25	3

4.2 Qualitative Analysis

The qualitative analysis of the chart contents was carried out in three stages. The charts were first reviewed in whole for *representational quality*. Representational quality was assessed by the ways in which the drawing elements, symbols and annotations were used

(Bar-Eli, 2013), the levels of complexity in which ideas were represented (McGown et al., 1998), and the degree of detailing in the sketches (Tovey, Porter and Newman, 2003). This was done in order to identify the operational strategies of participants in quick sketching for design divergence.

Following, rows of the charts were cut out and those belonging to specific sub-functions were brought together on separate sheets in order to review *the information content of the ideas* generated for each sub-function (Yilmaz, Seifert and Gonzales, 2010; Rodgers, Green and McGowan, 2000; Do, Gross, Neiman and Zimring, 2000). This involved a descriptive assessment of what the design solutions were about and how they offered to fulfil sub-functions, and was made according to the thematic grouping of sub-functions (Table 3). This assessment helped determine the design directions followed, topics and themes addressed, means offered for fulfilling sub-functions, interrelations between components, and interactions between the user and DFCMs. It was seen that the ideas offered design solutions grouped around: component configuration, form (shape, size, amount, texture, material), means (ways in which an operation is carried out), component location (in reference to overall DFCM), and consequences of operations.

The morphological chart contents were reviewed for a third time to understand *how participants actualised design divergence*. For this, the ways in which participants approached the task of filling in the morphological charts (e.g. how they began sketching, continued with idea generation, and completed the charts) were examined. Also, the various design thinking tactics that participants employed for idea generation (e.g. how they increased ideas in number, and diversified them) were studied (Börekçi, 2017). As a result, several factors that affected participants' performance in design divergence, as well as particular strategies that they employed for idea generation, were identified. The following section presents the findings, supported with insights gained from the four years of experience in conducting the project and observations on how participants used the morphological chart method.

5. Factors Involved in Design Divergence Using the Morphological Chart

It was seen that, in the design divergence task of filling in morphological charts, participants displayed performance in terms of the following abilities:

- time keeping (completing the charts within a given timeframe),
- producing quantity (amount of ideas for particular sub-functions),
- producing variety (degree to which ideas were diversified to explore various possible means),
- attaining complexity (extent of information conveyed with an idea),
- attaining creativity (extent to which ideas displayed out-of-the-box thinking).
- achieving idea quality (generating ideas able to address the design problem), and

- achieving representational quality (visually communicating ideas in an effective way).

The performance of participants in displaying these abilities ranged from low to high, depending on certain factors. The factors that affected these abilities were found to be based on preparations undertaken before carrying out the design task, and dynamics of the participant compositions in the groups. How the participants defined sub-functions towards setting their problem boundaries, and to what degree the product components were interrelated were also found to affect performance.

5.1 Preparations

Research on the problem area: Being informed on the problem area through product trials and product analysis contributed to the performance of participants. Participants were ready in terms of technical background, as well as familiar with various precedents.

Experience in using the morphological chart: Having prior experience with the morphological chart seemed to have positive impact on idea generation performances. The general tendency in groups with experience was for participants to work individually on all the cells in an entire row and generate ideas successively (Aspelund, 2010) rather than filling in random cells for whatever idea came first. This suggests that the participants understood the mechanics of the method and made use of it for design divergence.

5.2 Group Dynamics

Setting a common ground: Some groups carried out a short discussion on the possible relative arrangements that could be considered, bringing a holistic (from whole to parts) approach to the design task, also giving direction to the individual efforts of the group members. One group of mixed participants supported their process with collective online search for product examples.

Making strategic decisions: Carrying out discussions at the onset of the method helped groups make strategic decisions, such as how to name the sub-functions, which sub-functions to combine, which ones to consider as independent of others, and which ones to consider in relation to others.

Division of labour: Based on discussions, some groups divided labour. This mostly was about sharing sub-functions among group members. Five groups filled in the cells in a mixed manner; meaning, members freely filled in the cells that were closest to them, with ideas they could think of first for random sub-functions. Therefore, ideas represented in rows were not always indicative of an order of appearance; such that, some ideas were drawn upside down in reference to the chart orientation. These groups were those who used the morphological chart method for the first time.

Six groups distributed the sub-functions among members and worked individually on entire rows. These groups performed well in generating a succession of sketch ideas and completing their shares. One group filled in the charts conjointly; to begin with, each group member filled between 2 to 4 cells in each row, then the group members swapped sub-functions, and filled the remaining 2 to 4 cells in each row. This effort ensured that all the cells were filled.

Thinking on others' ideas: Group members also undertook the filling in of cells that remained empty. Some participants were observed to write over annotations to make them legible, go over sketches that remained weak, and use markers to highlight sketches, on behalf of the group. This helped to complete the charts, gave the charts a group identity, and ensured that group members were familiar with the ideas of others.

Working together versus working away: An initial group discussion and working together helped groups develop strategies in order to proceed with the work. A designer participant in one group was observed to sketch on behalf of a non-designer fellow group member who explained her ideas and gave instructions on how the solution should be represented. Two groups that did not carry out discussions at the beginning worked individually over the chart, and after a certain level of progress, group members preferred to work at separate desks on pieces of paper which they later pasted onto the chart. This indicates a tendency in working in parallel but away from the others and not in collaboration. These groups were those that had the lowest average number of filled-in cells per participant.

5.3 Boundaries of Sub-functions

Level of familiarity with sub-functions: Participants were familiar with the problem situation, and also had studied the product components. This made it easier for them to suggest alternative working principles from similar problem situations and transfer them onto the sub-functions of the DFCM (*e.g. hooks or winding springs for winding the electric cable*).

Degree to which parameters for sub-functions are fixed: Participants mainly generated alternatives in form when the problem boundaries were fixed (*e.g. carafe sits on hot plate*) and parameters known (*e.g. volume of water reservoir is compatible with volume of carafe*). On the other hand, participants generated alternatives in means for fulfilling sub-functions more, when parameters were not rigidly set (*e.g. accessing the filter housing somehow*).

5.4 Interrelations of Product Components

Level of complexity of components: Complicated components were studied more in depth compared to simple components, in terms of relative arrangements of sub-components, working principles, consequences of operation, interaction between other components, and form for functionality.

Level of interaction between components: Participants tended to explore the direct and indirect effects of their design decisions. The interactions of complex components with neighbouring components were explored more, compared to simple components. Participants isolated components totally independent of others such as carafe, or sub-components such as handle, in their form exploration. Less independent components were almost always drawn with neighbouring components.

6. Strategies for Idea Generation Using the Morphological Chart

A significant factor in participant performances in design divergence was the usage of various idea generation strategies. These were the design thinking and idea representation tactics that participants employed for effectively generating and representing ideas. The strategies were determined for beginning idea generation, carrying out effective idea generation, exploring ideas, diversifying ideas, and representing ideas.

6.1 Strategies for Beginning Idea Generation

Naming the sub-function: The way the sub-function was named indicated how groups decided to approach the sub-problem. The general tendency was to use nouns as the names of sub-functions for components that were relatively more independent, with fixed problem boundaries (*e.g. "carafe", "hot plate"*). In this case, form was explored more confidently. On the other hand, sub-functions were described in general terms for components that were more closely related to neighbouring components with problem boundaries not yet fixed (*e.g. "boiling and transferring water"*; *"keeping product components together"*). In this case, working principles and sub-component configurations were explored to begin with.

Finding sources for ideas: Participants used precedents, analogies and transfers as sources supporting idea generation (Figure 10). Participants used sub-solutions offered on precedents, meaning other DFCM examples (*e.g. drip nozzle, electric cable winder, water level indicator*). They used analogies related to form (*e.g. bubbles*), function (*e.g. stove*) or working principles (*e.g. water dispenser*). They also made transfers for sub-solutions from other product categories (*e.g. interfaces from electronics*).

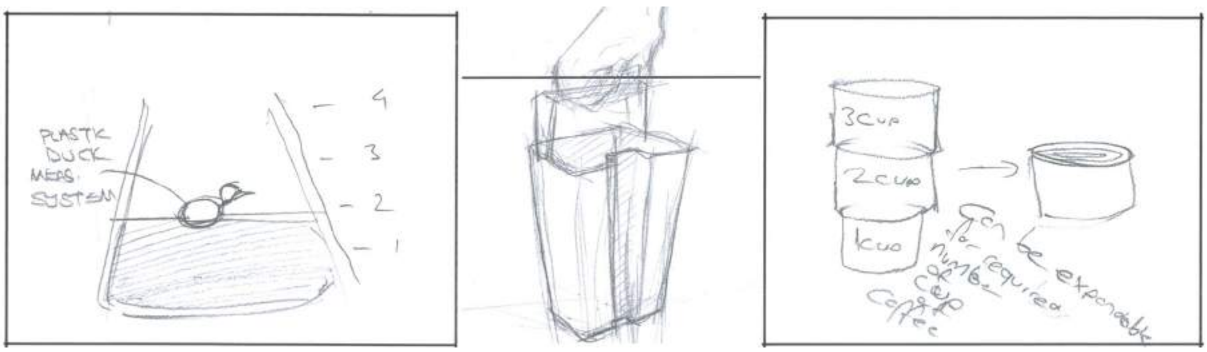

Figure 10. Left: Functional analogy of a rubber duck as level indicator (2015, Gp-J). Center: Handle solution from a precedent examined in class (2015, Gp-I). Right: Transfer of telescopic extension for expanding filter basket (2015, Gp-J).

6.2 Strategies for Effective Idea Generation

Thinking holistically: All groups started generating ideas for “product structure” or “relative arrangements” first, before moving on to other sub-functions. As for sub-functions, groups generally sketched a whole or partial product showing the position of a feature on the DFCM somewhere in the row. This was preceded or followed by close-up sketches of alternative solutions for the particular feature in the other cells. Participants also displayed the need to contextualise their exploration and even when they worked mainly on a particular feature, they still tended to show neighbouring components in their sketches.

Successive thinking: For groups that completed their charts without leaving cells out (F, G, H, I and J), a significant strategy affecting their performance was successive thinking. Once participants in these groups started idea generation, they aimed to complete an entire row (Figure 11). This supported goal-oriented thinking and variation of ideas. These groups were all formed from designer participants.

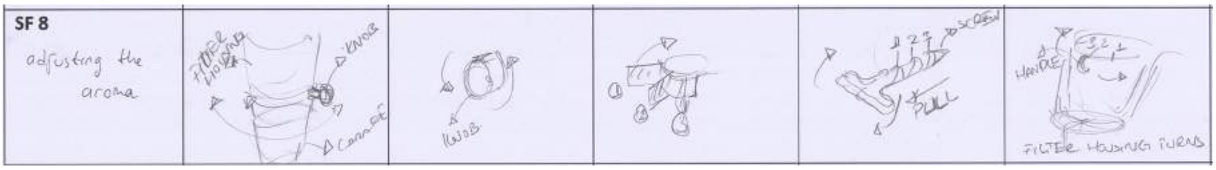

Figure 11. Successive thinking for variations, showing controls for adjusting coffee strength on filter housing as well as on their own (2016, Gp-L).

6.3 Strategies for Exploring Ideas

Exploring form: Form-related explorations were functional as well as aesthetic. One strategy was, deciding on an overall product form that was then broken down into its components, which were then explored (Figure 12, left and centre). Another strategy was exploring forms of components that were determined as most significant (e.g. *carafe*), and building the remaining product components around it. Material properties and surface qualities were also explored as part of form.

Exploring working principles: Explorations of working principles took place for: alternative ways of fulfilling same function; alternative configurations of components (Figure 12, right); and common or shared features in different components. The effects of a new working principle suggested for a sub-function were shown for the particular sub-function for which it was suggested, and also for its neighbouring components.

Exploring common means for realising different sub-functions: Some sub-functions common to multiple components such as controls, handles and lids, were solved in common ways (*e.g. common controls for on-off switches and coffee strength adjustment*; *common handles for carafe and water reservoir*; *common lids for water reservoir and filter housing*). Common means were seen as the feature identifying a product component family.

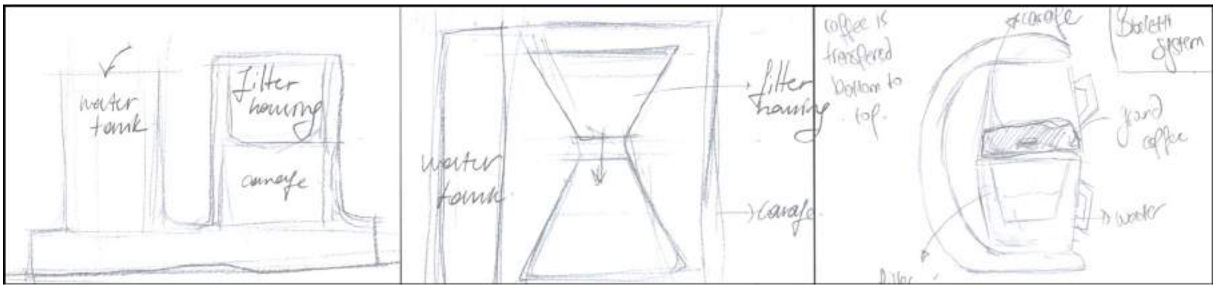

Figure 12. Exploration of form on same row. Left: Dispersed layout of components. Centre: Components divided from a volume by same group member. Right: Components reconfigured by another group member (2015, Gp-I)

6.4 Strategies for Diversifying Ideas

Thinking on consequences: Participants tended to consider the effects of their sub-solutions in terms of output as well as the consequential actions triggered in other components. Therefore, there were sketches showing components in various versions (*e.g. open/closed*) and in various situations (*e.g. before/after*).

Using parallel perspectives: Some sub-functions were explored in multiple rows besides the row dedicated to them; there could be sub-solutions offered for them in rows exploring other sub-functions. This means, participants did not isolate sub-functions and consider them to be entirely independent of others. They had the tendency of thinking on multiple design solutions simultaneously. Therefore, another significant finding was that cells generally contained multiple design solutions.

Shifting perspective: Participants varied their approaches to the sub-functions using certain tactics. These were: combining sub-functions (*e.g. water reservoir and structure*); eliminating sub-functions (*e.g. eliminating water reservoir altogether*); splitting sub-functions (*e.g. making a separable hot plate*); adding new sub-functions to a component (*e.g. funnel integrated lid for pouring in water*); adding new sub-functions as a component (*e.g. coffee bean grinder*); and suggesting alternative means for a sub-function (*e.g. using commercial water bottle instead of including a reservoir*) (Figure 13).

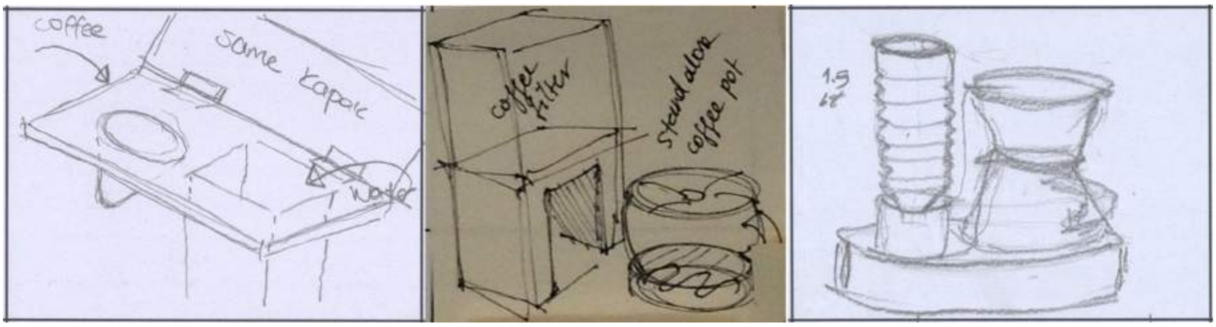

Figure 13. Left: Combined lid (2016, Gp-L). Centre: Split hot plate (2014, Gp-D). Right: Alternative means for the water reservoir (1,5 lt water bottle placed upside down) (2016, Gp-K)

6.5 Strategies for Representing Ideas

Varying drawing elements: The cells contained a variety of sketch types, ranging from simple 2D diagrams to refined 3D sketches. Sketches were supported with annotations, the contents of which relating to: *function, material, effect, component, input* and *output*. Sketches included arrows to point out to features and locations, as well as show directions of movement. Shading and texture were used to give three-dimensionality and depict form of product parts; colour was used to emphasize a detail, show graphical applications or represent various stages on interface displays. User hands were represented to show size, usage and order of operations (Figure 14, left).

Varying focus: Sketches contained a mixture of ideas shown on whole or partial products, or on close-ups of details (Börekçi, 2017). Sketches of whole DFCMs showed overall form, component configurations, alternative working principles and their effect on configuration, and features on a particular component in reference to the remaining of the DFCM. Sketches of partial DFCMs showed components in detail, some with neighbouring components to indicate location or to show how an operation of a component affects the next one. Sketches of isolated components or features were also made. These were generally studies of form, drawings showing how features work (*e.g. moving, rotating, retracting parts; steps of operation*); specific characteristics of the features (*e.g. texture, pattern*); hidden parts or sections; and features of the interface (*e.g. knobs, controls, displays*).

Varying level of sketch detail: The more complicated the components, the more detailed the sketches were (Figure 14, centre). Some cells with detailed sketches included multiple drawings of a component, which could be perspectives, orthographic views and sections. Detailed sketches showed nesting and moving parts in 3D, using sections or drawing open and closed versions of a component. Such sketches also showed the DFCM in different situations (*e.g. with or without a component; during operation; when hot/when cold*). Less complex components were generally mainly explored for form. These sketches remained two-dimensional; some had incomplete contours with missing lines, probably for the purpose of using time economically, or due to the visual information being sufficient (Figure 14, right).

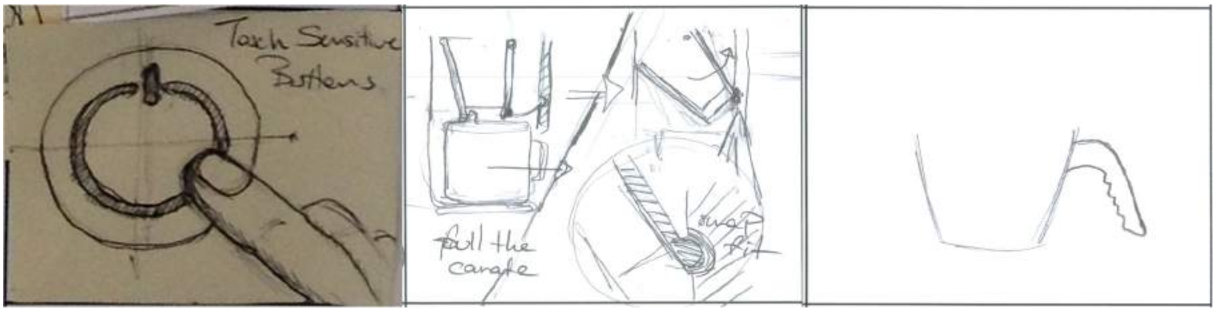

Figure 14. Left: Close-up sketch of a control with user's finger (2014, Gp-D). Centre: Detailed sketch with multiple drawings (2015, Gp-H). Right: Simple and incomplete sketch of a carafe showing handle (2015, Gp-F).

7. Conclusion

This study examined the performances of designers in using the morphological chart method for design divergence in idea generation. It was seen that participants treated the task as an opportunity for holistic and partial design exploration, and not mainly for the revision of possible means for fulfilling individual sub-functions. It is possible to make the following inferences regarding the findings of the study.

- The ways in which participants named sub-functions displayed the ways in which they approached the design problem (problem framing; Schön, 1991; Stompff, Smulders and Henze, 2016; Zahedi and Heaton, 2017), and also manifested variations in their level of abstraction (Teegavarapu, Snider, Summers, Thompson and Grujicic, 2007; Richardson et al., 2011; Smith et al., 2012). Sub-functions with fixed design specifications were named with nouns and explored freely in terms of form (e.g. “hot plate”; “carafe”). Those with parameters less rigidly set were named with functional descriptions, and explored more in depth in terms of means (e.g. “transferring hot water from water container to filter housing”).
- Although they were not guided in doing so, all groups collaboratively developed alternatives for tentative configurations representing the whole product first, and then broke them down for exploration (primary generators; Darke, 1984).
- This consequently allowed groups to set a common ground for design explorations, determine design divergence strategies and divide labour among members.
- When carrying out idea generation for a sub-function row, participants were inclined to think on multiple design features at the same time. Besides, they tended to continue explorations for some design features in other rows of sub-functions, in combination with new ones. They preferred exploring multiple components rather than isolated ones, demonstrating their tendency for thinking in parallel lines of thought (Lawson, 2000).
- Once working on a sub-function, participants tended to individually develop a succession of sub-solutions for completing the entire row at one go (Aspelund, 2010).
- Participants mostly considered components as interdependent and therefore explored the effects of their design decisions on the following steps of operation, related components and outputs.
- It was seen that designer participants were more accustomed to visual thinking with tactics that help explore a design problem, such as diversifying working principles and variating design ideas.
- They were able to use their 2D representation skills to demonstrate the consequences in different situational contexts, showing an ability in thinking in terms of process (*i.e. before, during and after*) and from the point of view of users (*i.e. how to, what if*).

The following direction of research would be to study the activities of design convergence carried out by the participants in the development of the final design proposals. This would require understanding their evaluation and selection processes of sub-solution alternatives to combine into overall design solutions. The main issues of enquiry in this case would be the criteria involved in the course, resolution of conflicts between selected sub-solutions, and decisions related to design embodiment.

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Problem Based Learning: Developing competency in knowledge integration in health design

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Abstract
Different communities, organizations, and people hold different views on their own and others' wellbeing. It is often challenging to balance different perspectives during the design process when the truth of medicine is competing with the truth of social media and the everyday experience of wellbeing of patients, caregivers, family and friends. In the context of the Masters of Health Design at OCAD University (OCAD U), we develop students' competency in working with truth through challenging students to engage with multiple 'truths' in the design process, engaging deliberately in identifying and working with multiple truth regimes as part of a problem based learning approach. This includes how truth regimes impact the understanding of a challenge area, techniques for engaging with stakeholders, communicating and developing concepts, and the process of seeking and working with feedback for refining and iterating, and finally in communicating project solutions. By engaging in problem based learning, students are exposed to the real challenges of different stakeholder perspectives and in particular how different truth regimes serve to impact what counts as legitimate knowledge and legitimate knowledge representation.

Key words
health design, knowledge, process, problem based learning, stakeholder engagement

1 Introduction

While design practitioners may enjoy the legitimacy to practice in a range of domains, this is often not the case in medical or health related settings where knowledge arising from the practice of design may be an unfamiliar process. As well, knowledge arising from design practice may be perceived as in competition or opposition to established forms of knowledge and knowledge production, such as the evidence base of bio-medicine, humanistic medicine, or the patient experience (Sellen, 2017). In thinking about different types of knowledge production and maintenance one might describe these as differences in style or regime – a truth regime. In the health sector, it could be said that there are several styles of truth regime commonly in operation that a designer working in the health domain might encounter and be challenged to work with, perhaps integrating these as part of the design process. As a student of health design, one of the competencies that is integral for success, is the ability to navigate and integrate truth regimes in the often-contested space of healthcare.

At first glance, the scientific truth of medicine and its evidence base would seem likely to dominate. This is the first challenge for students. In the first stages of understanding a project or challenge area, identification and interpretation of scientific sources of knowledge may be an unfamiliar activity for many students and may need to be supported through technique development in seeking and synthesizing medically related evidence for design. However, the role of the 'doctor' or physician can be a particular and dominant one, and may signal that the role of clinicians in a design related project can involve negotiation by the designer in, or with, a truth regime that is not based on evidence but on a humanistic approach. In the course of the M. Des. in Design for Health at OCAD U we support students to develop competency in integrating knowledge from different truth regimes as part of their learning process, recognizing also that design for health students themselves operates within their own truth regime, one that may privilege designer, process, prototype and designed object. With this paper, the intent is not to revisit conversations on design and science, discipline and practice (Cross, 2007), but to share the experience of a developing framework that prompts further thought on these topics in the context of design for health.

1.1 The truth regime

A truth regime can be described as a general politics of truth (Weir, 2008) comprising of: ways in which truth is identified and represented; techniques that indicate true or false statements; techniques for how statements are evaluated/or not as truthful; and the status accorded to those that speak 'truth', and, the manner in which truth is 'spoken'. The concept of the truth regime was discussed by Foucault in 1960s and 70s alongside ideas about knowledge and power, and in particular in reference to scientific and quasi-scientific truth in modernity (Foucault, 2000). Analyses of the concept of the truth regime and the implications of this idea for design are rare and even rarer in medicine or health. However, a few examples of its use to interpret biomedicine and the experience of health and wellbeing do exist (Larsson, 2013; Valverde, 2002). The ideas described in this paper, for instance, are drawn from the work of Lorna Weir (2008). Weir provides an interpretation of Foucault that highlights different types of truth regimes in addition to scientific and quasi-scientific truth – these form the basis of the design for health framework used in the context of graduate training in health design. Developing this work for relevancy to the health context and to design practice, the framework also draws on the work of Sam Ladner (Ladner, 2014) who uses Weir's work to advocate for the use of the truth regime concept in the practice of ethnography in the private sector. Both Weir and Ladner emphasize several types of truth regime that identify, represent, and present truth in different ways. A summary of four key styles of truth regime according to Weir (2008) and Ladner (2014) are as follows:

- Veridical truth – scientific truth based on the constant search both for error and new data
- Governmental truth – principally concerned with governing behavior and quasi-scientific
- Symbolic truth – represents truth through ritual and role, rending invisible truth visible
- Mundane truth- truth that arises from everyday experience, common sense or common knowledge

While these truth regimes may be operating in any domain, they are present in prominent ways in the health sector. In this paper, a framework for understanding and working with these different kinds of truth will be shared - including how it has been used as a graduate learning tool, applied to knowledge integration in the re-design of a geriatric psychology unit during a problem based learning engagement for Design for Health master's students at OCAD U.

1.2 Problem Based Learning in Health Design

Students of health design are supported in their exploration and mastery of knowledge integration in design for health contexts through problem based learning and the progressive development of design technique and critical thinking skills. The curriculum of the M.Des. in Design for Health at OCAD U is organized into a series of four problem based learning engagements, which are developed and executed with health sector partners. Projects are supported through embedded activities with these health sector partners as well as studio based learning supported by an interdisciplinary group of faculty members. The first two problem based learning engagements are supported by seminar based learning and it's in the context of these supporting seminars that key concepts from medical anthropology are introduced, the social science and critical sociology of biomedicine, and the concept of the truth regime. The supporting seminar structure provides an opportunity to explore and discuss the development and role of different design approaches and traditions. This includes the more veridical or scientific approaches of engineering, user centered design and usability, to the critical design and conceptual design approaches that are perhaps more symbolic, and the inclusion of co-design and participatory design techniques that that may support the mundane or everyday truth of participants. Students, at the same time, respond to the problem based learning engagement, choosing what design approach to take, how to organize their involvement with stakeholders, and how and what to research and prioritize in the design process.

1.3 Problem Based Learning – Geriatric Psychology Unit Re-Design

In the case of the geriatric psychology unit, the students were presented with a problem based learning engagement with a local rehabilitation center. The stakeholders presented the students with the purpose of the engagement – to develop a redesign of the unit within the constraints of its existing footprint and with special consideration for the particular needs of the patient population that it serves. One of the first steps for students was to try to understand what the unit's purpose is, and what types of patients the unit serves. With this first step in a project, students are engaging with different truth regimes.

How is the patient population defined? In medical terms? Or, in terms understood by nurses and clinicians on the unit, by family and friends, or the long-term care homes where many of the patients arrive from? Are they "Dr …'s" patients? Or are they defined by their behavior – which places them in the unit as a result of governmental forms of truth about their suitability/or not for a long-term care place? Students are challenged to explore the possibility that different truths about the unit and its patients, as well as its staff, family and friends, may be at play. In this way students learn from the challenge of negotiating different truths and the viability of different outcomes in terms of a design solution – a key aspect of problem based learning (Savery & Duffy,1995). It may be appropriate to decide to take a participatory approach in such a situation, as participatory techniques are intended to support multiple stakeholders and the politics of different positions (Robertson & Wagner 2012), but similarly, an evidenced based approach in which students interrogate the evidence base for data on dementia, behavior, and designed elements such as lighting, artwork, flooring, furniture and activities, may also be appropriate – in considering these decisions as part of the learning process. Students are asked to develop a rationale for their choices that demonstrate an awareness of different truth regimes, indeed a rationale and plan that makes use of different truth regimes in integrating knowledge to inform design.

2 Truth regimes in health

Layering onto the choice of the design approach, it is useful for students to understand how truth regimes operate in the health context – for instance with the physician or clinician there may be ritual and ritualized objects (for example the stethoscope), codified roles, and the storytelling (humanistic medicine) that reinforces certain beliefs and structures. What is key here is that perhaps unexpectedly this symbolic form of truth can be in conflict with bio-medicine or scientific evidenced based approaches (Mykhalovskiy & Lorna, 2004). Contrast this with the everyday truth of the patient – their experience of their wellbeing informing their beliefs and understanding of their situation and needs that arises out of continuous personal experience. Figure 1, illustrates four types of truth – mundane truth (here characterized as "life" to refer to the lived experience), symbolic truth, governmental, and scientific truth, with reference to the concept of wellbeing. In this brief exploration of the concept of wellbeing we see several aspects of what Foucault describes as the "truth game"[4], namely different roles or figures that are able to "speak the truth", and specific reference points for each type of truth – for example the evidence or procedure of science as a reference point for scientific truth. When we consider this representation, it illustrates how certain types of truth regime may be in conflict with each other and how some may be more open to change than others.

Life	Symbolic	Governmental	Scientific
"The mundane everyday experience of health."	"What our leaders tell us about health."	"Eligibility of the patient – category, behavior."	"The science of health – concepts, experiments, and data."
Anyone Self-evident Truth vs Lie	Only specific figures Legitimate story Ritual	Administrator or Holder of policy Policy and Procedure	Scientists The evidence Procedure

Figure 1. Four Truth Regimes in Relation to Wellbeing

2.1 Scientific Truth in Health Design

In scientific truth, there is always the possibility for new evidence, new data or ways of measuring that allow for a change in direction. In relation to the dementia patients in the geriatric psychology unit, there is new science on dementia every day. In terms of a design approach working with scientific truth, students are encouraged to develop skills in working with the evidence base, interpreting scientific data and synthesizing evidence. Part of this process of building competency also includes a critical understanding of the development of evidence based medicine and the way in which evidence based approaches are used in the health sector to organize innovation and change. Models of healthcare intervention design are compared to design approaches to identify opportunities and challenges for integration. In the case of the geriatric psychology unit re-design, students developed evidenced based scoping reviews that demonstrated to their stakeholders that they respect and understand the scientific truth relevant to the unit. They then presented design concept scans that demonstrated how such scientific truth can be reflected in design choices and outcomes.

It is worth considering here if there is an equivalent to scientific truth in design? Evidence based design in healthcare is relatively well established, however, this is not what is intended by a scientific truth equivalent in design. Instead the truth regime concept can be used to challenge students to consider how design is represented in the evidence base – if at all. This draws attention to how invisible design work can be in a sector dominated by the randomized controlled trial, case study, and case note as the mechanism for knowledge representation. The equivalent for design may be design museum archives, prominent design magazines and blogs, perhaps even Instagram or Pinterest? What does a scientific approach to gathering and integrating knowledge from these sources involve? These and other questions become discussion points to challenge students to see how design insights might be expressed to stakeholders both through process and forms of knowledge representation. Out of this discussion come proposals for discovery phase design work including a process of capturing and expressing design examples through forms of scientific truth production and representation such as mini-scoping reviews.

2.2 Mundane Truth in Health Design

The staff on the unit experience new patients on a regular basis, and patterns of behavior may emerge through everyday experience of the work of the unit. The staff may share a collective mundane truth about how the unit works, the type of patients on the unit, and how certain designed objects or spaces serve to support or not the work of the unit. A common response from staff would be “We know the bathroom needs redesigning” based on the everyday experience of the difficulties persuading patients on the unit to accept intimate care (a term that comes from the governmental truth regime operating in the health sector and a criterion for deciding if a patient remains eligible for home or long-term care). However, further probing and exploration of intimate care of older adults in care settings as well as some basic design ethnography revealed that the ‘problem of the bathroom’ starts well before the bathroom is experienced. This allowed a reframing of the problem away from the bathroom itself to the experience of undressing and preparing for bathing. As mundane knowledge is open to change through everyday experience, students were encouraged to use a mundane and everyday story telling technique to communicate this reframing to stakeholders. In this way, the mundane truth of staff is respected, acknowledged and built on by students.

In the case of the geriatric psychology unit there is a barrier to interact with patients due to the advanced level of cognitive decline, however, in many other problem based learning engagements, working with patients, family and caregivers would be expected. The practice of experience based co-design is a common approach now advocated in the health sector to specifically address the inclusion of patient experience (Bate & Robert, 2006). While there has been little attention paid to forms of mundane knowledge generally, the domain of health is the exception. Sociology and anthropology of health does seek to understand the relationship between biomedicine and lay knowledge/experience. Experienced based co-design has emerged as a counterpoint to evidence based approaches, with its emphasis on patient narratives, emotional touchpoints, and video based story telling. In the same way as students compare design approaches to evidenced based approaches, students are encouraged to compare and critique experience based co-design, and decide whether or not the techniques central to experienced based co-design will support the integration of mundane truth. One of the challenges for students in this regard is the number of other design based techniques that come from design approaches that also serve to represent mundane truth – personas and scenarios, for instance.

2.3 Symbolic Truth in Health Design

Symbolic truth manifests truths that are thought to exist but are not visible, and this manifestation is often conducted in particular ways that often include ritual and storytelling. Authorized speakers of symbolic truth are usually power holders, for example the nurse practice leader, the surgeon, or representative of a clinical specialty, can be counterweights to those in power or those in dominant positions, for example, patient advocates, representatives with lived experience, or campaigners for health care access and equity. Organizations may also be ‘keepers’ of symbolic truth. The Mayo Clinic may hold symbolic truth about practice change, for instance. Symbolic truth will be familiar to designers, Jonathan Ive (Chief Design Officer, Apple Inc.) speaks the truth on design for Apple, for example. The ritual of the studio ‘crit’ or critique in which the faculty speaks the truth about whether a student’s work is ‘great design’ or not, is another example. It is interesting to consider what truth regime may operate in a design school – who decides what a great design is? Is great design only visible when it is declared as such, if so, then declaring something a great design is a symbolic gesture, and a claim that only certain individuals have the legitimacy to enact. A design may be declared incoherent in the same way that quasi-religious or symbolic truth regimes declare an opposing truth as ‘incoherent’[4].

In the case of the geriatric psychology unit, and indeed across the long-term care and retirement care sector, there is symbolic truth in the idea of “home” and its importance to supporting the care of the elderly in contexts that are not “home” (Rubinstein, 1990). Indeed, stakeholders will routinely state “this is their [patients] home”, even though the average stay is 3-6 weeks, or in dialogue on the kind of qualities that are important to consider in the re-design of the unit, state that “it needs to look like a home”. Typically, those who make these statements do so in public venues, in front of others, and speak from a position of authority over the unit, its staff, and the design project. In considering the re-design of the unit, scientific truth together with mundane truth, and the integration of knowledge across these through the design process, suggests a re-design that does not replicate home. Students are then challenged with how to address the symbolic truth of the idea of “home” and to communicate proposals that avoid being interpreted as “incoherent”.

2.4 Governmental Truth in Health Design

Governmental truth generally operates to express truth through the application of category and definition – thereby facilitating the control or direction of behavior including the behavior of organizations, individuals, and technology. Its most obvious manifestation is in policy, programs, guidelines, protocols, algorithms. Authorized speakers of governmental truth can be a faceless bureaucracy, administrators, computer system, or system structure. Governmental truth is a common form of truth in health contexts largely due to the governmental structures of healthcare funding, but also accreditation structures, and the development of practice guidelines to support the aim of quality and efficiency. Design and engineering has its professional associations, accreditation structures, and design guidelines and regulations, as well as the ever present ‘health and safety’. In the case of geriatric psychology, there are strict criteria for determining if a person is eligible for admittance to the unit, and equally strict criteria around their length of stay, expectations of care delivery, medication restrictions (sedation for instance) that become the preoccupation of staff on the unit as all these examples determine funding and performance outcomes. This preoccupation can serve to stifle individualized care, and make creative adaptations to the unit difficult to realize. Acknowledging and integrating outcome measures that would support unit performance review in relation to a design project’s outcomes may be considered a distraction by students but these metrics may be vital for a healthcare client to justify any spend or staff time. Outcomes and guidelines can easily be translated into design requirements that, given funding and a relatively longer timeframe, may be tested against existing systems of audit and control. Challenging students to develop proposals for testing and outcome measurement develops competency in thinking across truth regimes and integrating with system structures.

3 Building Competency in Knowledge Integration

Using a truth framework to support students' understanding of problem based learning engagements also supports the development of knowledge integration skills. In Table 1 below, which shows a framework containing high level examples from the geriatric psychology unit redesign project, each type of truth regime is identified, along with questions that form a "truth game". Introducing this framework to students in their first semester, the framework is used to support higher-level thinking about the concept of health, wellbeing, and biomedicine. With an initial exposure to social science and medical anthropology perspectives on health and wellbeing, humanistic medicine, and biomedicine, students are ready to work on problem based learning engagements. Working with the framework includes several activities: the framework provides a structure to seek out new knowledge across truth regimes; the framework encourages reflection on the diversity of stakeholder perspectives; the framework provides a reminder to students to actively integrate knowledge across all truth regimes.

Table 1. Truth Game Design Tool

	Mundane	Symbolic	Governmental	Scientific
Story Summary	Nurses say the alarms don't work	Our program is world class	Patients should not be sedated unless criteria are met	Patients are diverse with different needs
Who speaks the truth?	Nurse, Patient, family member	Practice leaders	Administrator	Gerontology researchers
Truth vs. Non-Truth	my experience vs. yours	"our program" vs everything else	definition of criteria vs. other factors impacting care	data on dementia and science of 'cognitive decline
Knowledge is understood as…	Experience	Thought leaders	Ministry review	Studying dementia
Knowledge is represented by …	Anecdote/story	Through story and ritual	Policy	Evidence base

Truth regimes engage in what Weir refers to as "signifying practices" (Weir, 2008) – the representation of truth as a second stage whereby truth is translated via speech, writing, and visual arts.

The framework prompts questions about the role of design, how truth regimes operate in design and design teams, and how truth operates in the process of design. In the case of design, the prototype or model is a form of truth representation. The framework implies that truth regimes share and represent knowledge in different ways and can be used in concert with health sector models of knowledge integration familiar in public health (Gagliardi, Berta, Kothari, Boyko & Urquhart, 2016). For instance, among caregivers for older adults with dementia, knowledge may not reside in the evidence base, but it may be shared in sites for story telling such as online forums, and community centers. Recognizing this, prompts students to consider design engagement techniques that address these sites. The role of the designer is also brought into question by the framework – questioning the role of the designer in integrating knowledge across truth regimes, the position of the designer vis a vis making judgements of the value of certain types of truth over others. Does the nurse's mundane knowledge of the everyday running of the unit take precedence over the evidence base on flooring choices? What responsibility does the designer have to different truth regimes? How might designer's ideas and concept work fit within a truth regime or not? And how can the design team integrate different truths in a timely and practical manner?

One of the outcomes of developing and using the truth framework has been a growing realization of the need for design's truth to be represented in a way that is visible across or within different truth regimes. This prompts the question, in terms of the outputs of a design process – the prototype, the blueprint, etc., how might we develop ways in which design work becomes visible? For instance, for work to be considered in health innovation processes informed by the evidence base, it has to be present in the evidence base in a way that confirms to the truth regime of science. Sketches, photographs are usually not considered, but outcome measures and trial data are. We have discovered numerous design projects addressing design for dementia for instance, that have no visibility in the evidence base, nor do they feature in sites of mundane truth. So, in addition to challenging ourselves and our students to work across different truth regimes during a design project, we are also challenging ourselves to communicate our design work across truth regimes. This includes submitting work to health conferences and journals with our healthcare partners, creating social media assets and communication output for lived experience groups, and engaging in exhibition, and briefing notes that be shared with policy makers.

4 Conclusion

The experience of developing and implementing the truth framework, to support knowledge integration in problem based learning in health design, has been an additive experience for faculty and students. It is also a challenging model to implement as it requires engagement with the evidence base and evidence based practices, faculty competency in outcome identification and measurement, and engagement with techniques that are informed by medical anthropology and medical ethics. For students, it can be frustrating to divert time and resources to what some perceive as non-design activities. However, the potential for creative and integrative responses to project challenges informed by the use of the truth regime framework is there. Engaging intellectually with the idea of "truth" and then translating this to the practicalities of design engagements with stakeholders, serves as a real test of the idea and is an appropriate challenge at the graduate level in design education. It also serves to highlight conceptual overlaps between design approaches and truth regime which is proving useful in iterating on design techniques and on hybrid approaches to design in health that integrate across truth regimes.

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Design for Manufacture (DFM) within Professional Practice and its Relationship to Design Education

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Abstract

This research set out to assess the importance of Design for Manufacture (DFM) within the industrial design process, understanding how it is taught, and comparing this to the requirements of professional practice. A mixed methods approach was applied in, collecting a combination of both quantitative and qualitative data through two questionnaires. The first questionnaire was directed at current and graduate students from the Industrial Design (ID) and Product Design (PD) courses at Loughborough Design School. The second questionnaire targeted design companies that had previously employed Loughborough students in either placement or graduate roles. The results of the two questionnaires were then analysed individually before comparing a selection of directly corresponding results.

The results from the primary research showed that both students and companies agreed that DFM was a key skill utilised within professional practice. In both cases, DFM was regarded as more important than sketching and sketch rendering, supporting findings within the literature review that the role of the designer has changed. It was discovered that the main benefit of a professional designer implicating DFM during the design process was an overall reduction in cost. It may be concluded that, although the teaching of DFM at Loughborough Design School supplied the students with some knowledge, it does not entirely meet the requirements for professional design practice.

Key words

design for manufacture, professional practice, design education

Introduction

It has been well recognised that the role of the designer is changing (Gemser & Leenders, 2000). However, it is not yet fully understood whether this change is reflected within design education. Although there are many skills that the designers require for their role (Hurn, 2006), it has been found that one of the most important areas within the design industry, is Design for Manufacture.

Design for Manufacture (DFM) is the relationship between design and manufacture in order to improve performance and quality whilst reducing cost (Corbett, Dooner, Meleka, & Pym, 1991). This research will use this working definition, to find out whether DFM is being taught sufficiently within undergraduate education to prepare students for professional practice.

The aim of this work was to assess the importance of Design for Manufacture (DFM) within professional practice, comparing how it is taught within education to prepare students for industry. In order to fulfil this aim, the following objectives were achieved: a review of literature on the role of DFM within both professional practice and education; an investigation into the understanding of students' knowledge of the importance of DFM; an investigation of the skills that design-based companies require from placement or graduate students; a comparison of the opinions of the students and companies to fully understand if the teaching of DFM is relevant to professional practice.

Design For Manufacture (DFM)

'Industrial Design is the professional service of creating products and systems that optimize function, value and appearance for the mutual benefit of user and manufacturer' (IDSA, 2016). It is often mistakenly assumed that an industrial designer is only focused on the aesthetics of a product (Norman, 2011), however, recently it has become apparent that designers need to have an understanding of engineering, production processes, Computer Aided Design (CAD), as well as the more typical design techniques (Nichols, 2013). This is backed up by Gemser and Leenders (2000) who state that the role of the industrial designer focuses not only on aesthetics but on other areas, such as ease of manufacture, ergonomics and efficient use of materials. Initially, it was confirmed that the role of the designer had changed, progressing from the traditional role, who solely focussed on craft based skills: sketching, modelling, detailing and rendering (McCullagh, 2010), to the newly developing role where additional knowledge of engineering based skills such as DFM and CAD are required. Due to the varying nature of the design process, Baxter's (1995, pp. 261-265) three stage theory - concept stage, design development and detail design - was selected because of its simplicity. Next, the term DFM was defined as the combination of both design and manufacture working simultaneously to improve cost, quality, lead times and performance (Susman, 1992).

Previous research has established that a recent increased investment of industrial design in new product development has led to the financial success of companies such as Apple and Phillips (Gemser & Leenders, 2000). This is because an industrial designer has the ability to improve product appeal and build brands, whilst minimizing manufacturing costs (Ulrich & Eppinger, 2003). Research has highlighted that Design for Manufacture (DFM) should be part of the modern designer's tool kit. Susman (1992,) states that DFM, within new product development, is the combination of design and manufacture working simultaneously to improve cost, quality, lead time and performance. It is established, from a variety of studies, that one of the best ways to minimise manufacturing costs and reduce the labour-intensive assembly costs in new product development, is to apply product design techniques (Dewhurst & Boothroyd, 2003).

Well executed DFM should lower the cost of manufacture without detriment to the product quality. It also diminishes the lead times, as it will reduce the number of iterations from the industrial designer, which would otherwise have implications to the economic cost. It can play an important part in the commercial success of a product (Ulrich & Eppinger, 2003). Langowitz (1987) clarified that traditionally it was thought that design and manufacturing should not work together and that there should be clear definitions between the two. This has been described by Boothroyd (1994) as an 'over the wall' approach. A designer completes their work, and passes it on to manufacturers, who then deal with engineering issues, having had no input at the design stage. A financial cost may be incurred through this lack of simultaneous approach as manufacturing and assembly issues commonly arise. Furthermore, it has been discovered that by considering DFM early in the design process, the number of parts, fixings, manufacturing operations and assembly times can be reduced. The costs of these changes are highlighted in figures 1 and 2. Both diagrams show that the cost of making a design change increases as the design process progresses. Evidence shows it is more efficient to make changes at the beginning of the design timeline, as this is where the most influential decisions on manufacturing costs are made, but the smallest amount of investment is required (Magrab, 1997). This is confirmed in a study by Rolls-Royce that found 'design determines 80% of the final production costs of 2000 components' within their vehicles (Corbett, et al., 1991). Figures 1 and 2 depict the benefits of DFM within the design process.

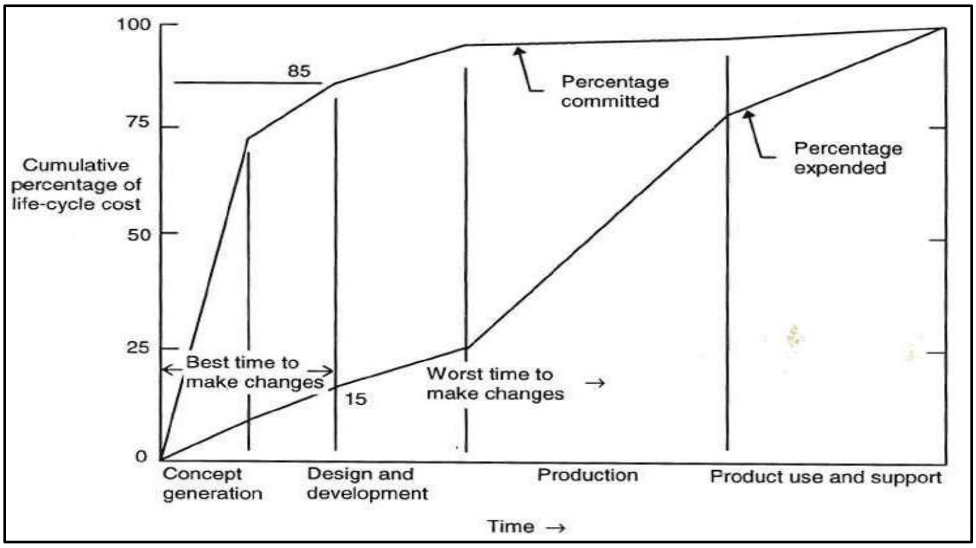

Figure 1. Cumulative product life cycle costs at the various stages of the product realization process (Magrab, 1997)

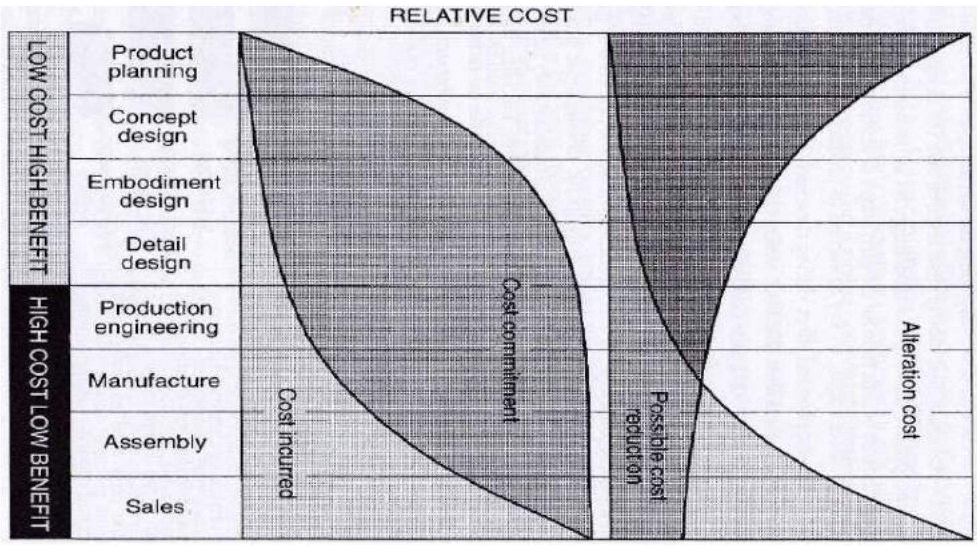

Figure 2 - Costs and benefits of different design stages (Baxter, 1995)

Ulrich and Eppinger (2003, p. 196) state that the design process is not common to all practices and vary from each firm, or even project. They outline a generalised industrial design process into 6 stages: investigation of customer needs, conceptualisation, preliminary refinement, further refinement and final concept selection, control drawings and, finally, coordination with engineering, manufacturing and vendors. Baxter (1995, pp. 261-265), however, simplifies the design process in just 3 stages: concept design, embodiment design/design development and detail design. He also explains how these stages overlap with one another with no clear finish or end.

A further body of work also expresses the design process in three stages: explorative phase, transformation phase and convergence (Lal, Gupta & Venkata Reddy, 2005), which are directly comparable to Baxter's theory. Therefore, this research will use the three stages defined by Baxter (concept design, design development and detail design) to explore DFM's role within the design process. Thus far, the research explored has highlighted the benefits of the industrial designer's application of DMF techniques early within the design process, to benefit new product development (Periyasamy, Sundaresan, and Natarajan, 2015). However, in reference to education, little has been published regarding the extent of students understanding of DFM, and how it can be applied to professional practice (Li, and Lockett, 2017).

The undergraduate teaching of Industrial or product design is a relatively new subject area, designers needing a broad range of skills from a number of disciplines (Hurn, 2016). McCullagh explains that the expanding scope of design means that craft techniques that designers are traditionally skilled in (sketching, modelling, detailing, rendering) have a lesser importance in the newly developing role of the designer. He goes on to suggest that the ignorance towards production techniques and industry dynamics leads to designers losing credibility (McCullagh, 2010), further suggesting the need to acknowledge the designer's changing role. It is therefore important that this change is also embraced within education (Favi, Germani, and Mandolini, 2016).

This study will focus on Loughborough Design School as the chosen educational model, in order to discover whether the teaching of DFM is sufficient for professional practice. At the Loughborough Design school (LDS), there two major undergraduate courses: Industrial Design and Technology BA (Hons) and Product Design and Technology BSc (Hons). The major difference between the two programs is that Product Design and Technology students are taught engineering based subjects (mechanics and electronics) whereas Industrial design and Technology students focus more heavily on the traditional design techniques (Bingham, Southee, & Page, 2015)). In the context of this research, an Industrial Designer (ID) is one that has taken part in the Industrial design and Technology BA course at LDS, whereas a product designer (PD) is one that has taken part in the Product Design and Technology course at LDS. The term designer will refer to the general population of industrial and product designers. Figure 3 outlines the basis of what is involved at each stage.

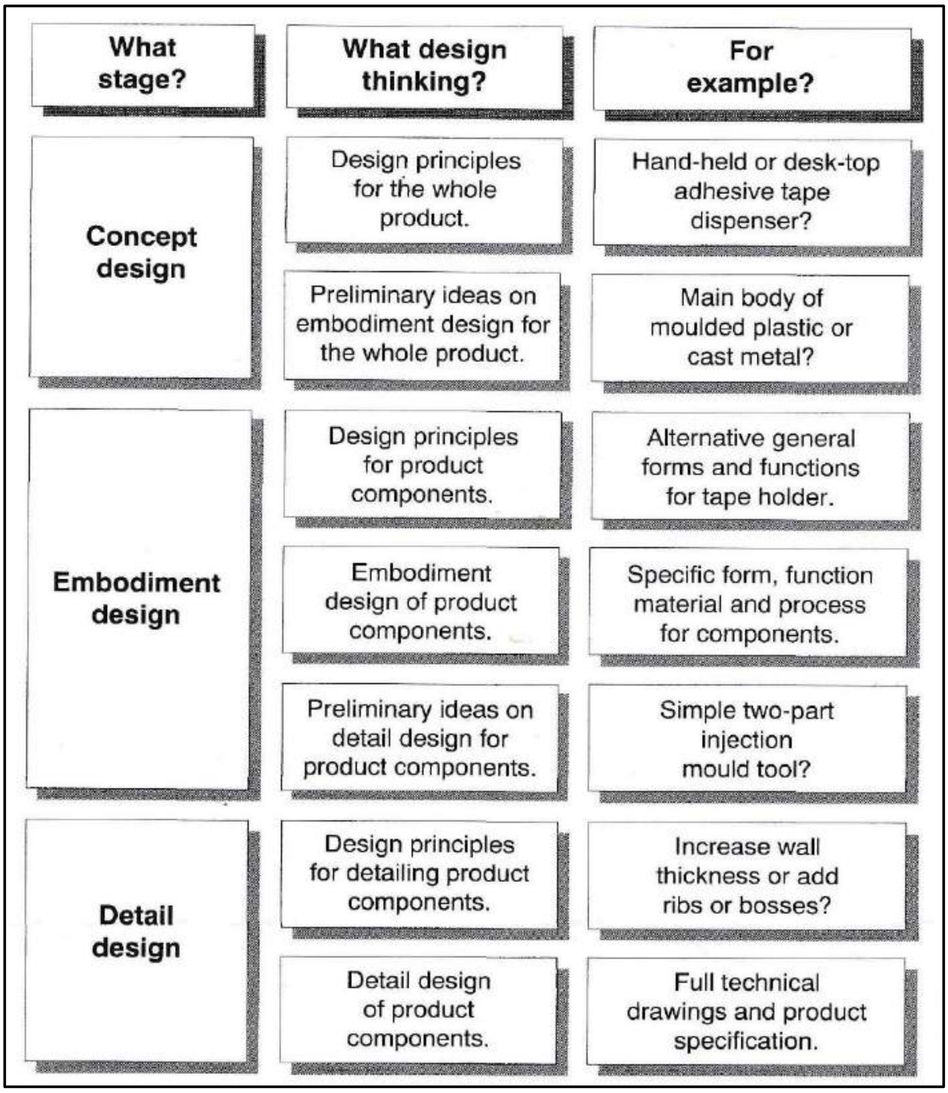

Figure 3 - Stages of the Design Process (Baxter, 1995)

Both ID and PD students have the option of a four year 'sandwich' course that provides the opportunity to work within a company, gaining professional experience. This is understood as a placement year in which 83% of students took part within 2016 (Loughborough Design School, 2017).

For the past fifteen years, students at LDS on both ID and PD courses have taken part in an injection moulding project which teaches applied DFM techniques. This gives the students an opportunity to implement DFM skills whilst designing a plastic widget, therefore, introducing them to real world design issues. Initial feedback from students, companies and examiners has been positive (Marshal & Page, 2016). However, there is limited understanding of the extent of this success, for example: would the course allow the designer to integrate into a design team with little or no further experience in DFM. Through further investigation, it appears that the commercial importance of DFM has not been explored (Betancur-Muñoz, Osorio-Gómez, Martínez-Cadavid, and Duque-Lombana, 2014).

Methodology

The literature review has highlighted the benefits of DFM within the design process, specifically highlighting its advantages when applied in industry. However, it was also acknowledged that it is not yet understood whether these advantages have been fully integrated within design education. Therefore, primary research has been undertaken to further understand the benefits and effectiveness of DFM with both the ID and PD course at Loughborough Design School.

A mixed methodology approach has been used. The method, which has recently increased in popularity, combines both qualitative and quantitative data (Robson & McCartan, 2015). The quantitative data will provide statistical results, whereas the qualitative data will provide further understanding (Barbour, 2014). This has been achieved by conducting two questionnaires: one directed at undergraduate or graduate students from the ID or PD course at LDS and the other directed at companies that employ LDS students as either placements or graduates. The two viewpoints allowed for data to be compared in order to validate the results. A questionnaire has been used to get the widest range of viewpoints, creating a more accurate representation of the population, as well as being a cost-effective method (Davies & Hughes, 2014).

The quantitative data will be amassed from a series of questions providing nominal and ordinal data. The nominal data will create a series of categories in which the ordinal data can be subdivided. This ordinal data will give the participants a chance to provide their opinion using scales or multiple choice answers. Any questions that require a scalar response will have a measure of '1' to '5', where the positive and negative ends of the scale have been kept consistent to avoid confusion for the participants, as well as making the results easier to decipher. This data has been represented graphically to prevent a 'lengthy and cumbersome' text based paper (Walliman, 2014). Furthermore, some data points will be analysed using mean values to determine overriding results from the spread of data.

The qualitative data will arise from a series of open ended questions. These responses will be analysed by grouping words and phrases into trends so that reoccurring themes can be identified. In addition, qualitative research unpicks and makes visible particular variables, providing a 'fuller picture' of the results (Barbour, 2014). The questionnaires took the form of an online survey due to the simplicity of setting up and the ease of sending out and collecting the results. The student questionnaire was sent out via email as well as being shared on a social media platform. The company questionnaire was emailed directly to the participant or passed on via current placement students.

The limitations of a questionnaire must be considered. It cannot be guaranteed that the participants will answer honestly. By targeting two separate parties and comparing the results, hopefully it will highlight and enable the removal of any anomalies. Furthermore, the title of the surveys suggests focus toward DFM, which may subconsciously bias the results. A blind questionnaire asking similar questions would be useful to validate the data. When analysing the results, each questionnaire was explored individually before comparing answers. A selection of the questions in both the student and company questionnaires are directly comparable and these have been analysed together to highlight any contradictory or similar opinions.

Results

Student Questionnaire

A total of 46 students took part in the student questionnaire. All the students that took part were graduates or undergraduates from the Industrial Design or Product Design courses at Loughborough Design School.

Nominal Data

The questionnaire directed at students had an almost even representation from the ID course (47.8%) and PD course (52.2%). This meant that even comparisons could be made between the two categories. The proportion of graduate to undergraduate however was uneven, with 73.9% the responses coming from Undergraduate students and only 26.1% from graduates. To overcome this deficit, the results will be looked at proportionally to each category rather than nominally.

The final question providing nominal data, wanted to find what professional experience the designers had undertaken. The options given were Graduate job, Placement year, Both or None. The data showed that 92.3% of the questionnaire population had at least taken part in a Placement year. Of the graduate students, 75% had experience from both a placement and a graduate job. From the population of undergraduate students, 91% had taken part in a placement year. Only 8.7% had no work experience at all, whom were all undergraduate students.

Areas of Importance and Improvements

This section of the questionnaire gave the participants checkbox style questions. Primarily, the students were asked to select the four skills that were most relevant for professional practice. The data shows a strong bias towards Computer Aided Design (CAD) with 93.5% of all the students seeing this as a priority. This was closely followed by DFM (76.1%), before sketching and sketch rendering (56.5%), and then visual 2D presentation (50%) (figure 4). Areas that were deemed noticeably less important were sustainable design (4.3%), marketing (13%), mechanics (15.2%) and electronics (4.3%).

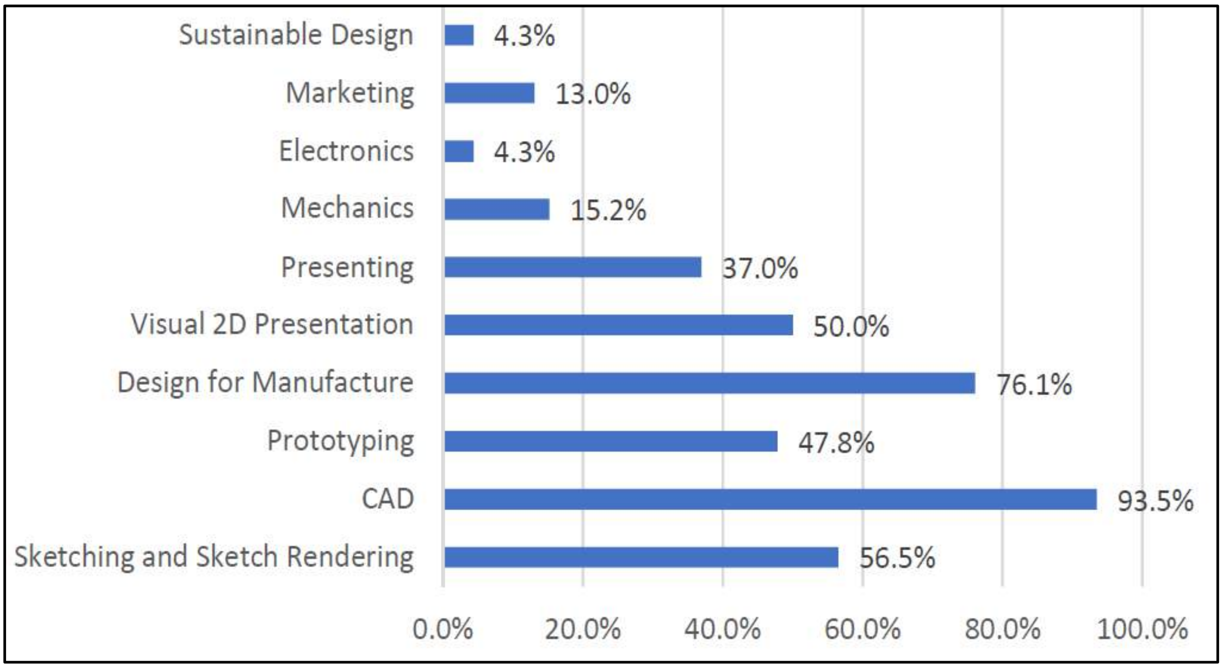

Figure 4: Selection of skills the students understood to be the most relevant to professional practice

After selecting the subject areas most relevant to professional practice, the students were asked to decide which of those areas LDS needed to improve. DFM was the most frequently suggested subject area with 65.2% selecting this answer (figure 5). Marketing was the second most popular answer (47.8%), followed by electronics, Visual 2D presentation and CAD, all with 37% of the population suggesting that these subject areas needed improvement. When comparing the different subject categories, graduate and undergraduate, ID and PD, there were no significant variances in the results.

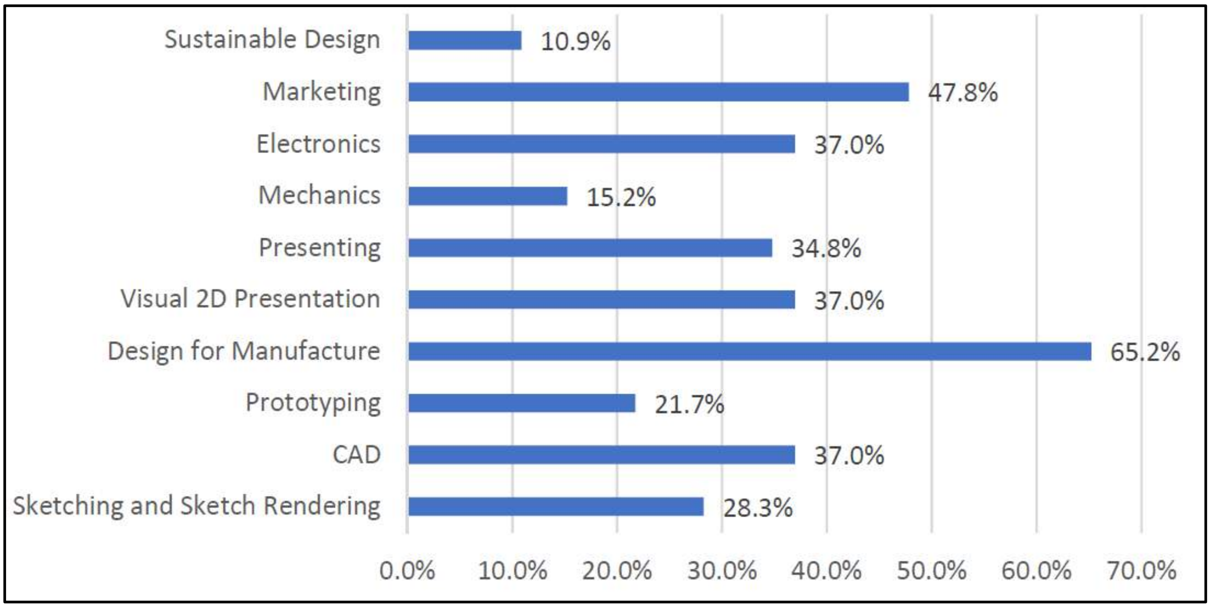

Figure 5: Areas of the LDS education that students feel needed improvement

DFM Teaching

The students were asked for their opinion as to whether they thought that LDS had improved upon their knowledge of DFM. The results showed that 41.3% agreed and 19.6% strongly agreed, evidencing that a majority felt that their knowledge of DFM had improved to some extent. When exploring the comparisons between ID and PD students, a greater proportion of ID students strongly agreed, whereas the PD students tended to agree with the previous statement. However, the differences between the results were not clear enough to make any decisive conclusion.

Subsequently, the participants that had worked in industry were asked if their knowledge of DFM learnt at LDS was sufficient for their graduate or placement role. This was gauged on a '1' to '5' scale, with '1' being strongly disagree and '5' being strongly agree. The results were relatively evenly distributed either side of the neutral answer ('3'), of which 38.1% selected. A total of 35.7% agreed or strongly agreed, whereas, 26.2% disagreed or strongly disagreed with the statement. When comparing the results of ID and PD students, there was some notable distinctions. PD students were more positive, with a mean result of '3.3', yet ID students were more negative, with a mean result of '2.6'.

The students were next asked to provide qualitative data discussing any differences between their university and professional understanding of DFM. Almost all the responses were in relation to the injection moulding project carried out at Loughborough Design School, in which students are asked to design a plastic widget. When analysing the data, the most common trends were the limited teaching of: cost, mass manufacturing techniques, and real world injection moulding knowledge.

The lack of real-world injection moulding knowledge was the most popular answer. This was due to the restricted teaching of moulding techniques that are essential for mass manufacturing within industry. It was also suggested that more knowledge on other mass manufacturing techniques should be provided. Furthermore, cost was a key element expressed by many of the participants as a vital part in professional practice but had not yet been considered within undergraduate education.

DFM Understanding

Many of the students claimed to 'always' consider DFM when they designed a new product (45.7%). 37% claimed that they 'often' considered DFM and 15.2% 'sometimes' considered it. Only one participant responded saying they rarely considered DFM when designing a new product. The results were broken down into subcategories. This found that most graduates would 'always' consider DFM, whereas undergraduates would 'often' consider it. Similarly, when comparing PD and ID students, it found that the PD students were more regularly considering DFM than ID students when designing a new product. However, there was less difference in these results than between graduate and undergraduate students.

Furthermore, a basic knowledge test, comprising of three questions, was included within the survey. The first question asked the participant to state three fundamental aspects of DFM which should be considered in the development of a new product. This question sought to assess whether the participant had a basic understanding of DFM. Out of those that answered the question (43 out of 46), all of them seemed to grasp a basic understanding. There were 6 different answers given, of which the most common was cost, with a response of 67%, followed by manufacturing method (58%) and thirdly material selection (47%).

Further to this, the students were asked to state at what stage in the design process they believed DFM should initially be considered. The participants were given three stages outlined by Baxter's theory on the design process: concept design, design development, detail design (Baxter, 1995). The data shows that 56.5% of participants believed that DFM should be considered at the second stage during design development. 32.6% of the population selected the concept design stage and only 10.9% selected detail design stage. The overall results were divided into groups to visually compare undergraduates and graduates. Graduates from the LDS believe that DFM should be considered at the initial concept design stage (58.3%). Whereas most undergraduates selected the second stage, design development. When comparing ID and PD, there was almost no difference.

Subsequently, the student's understanding was tested further by enquiring: at what stage is the largest proportion of manufacturing costs determined? Over half the participants selected design development, 30.4% selected detail design, and only 17.4% chose concept design. Once again comparing graduate to undergraduate students, it was clear that the graduates had a better understanding of applying DFM techniques earlier in the design process. 41.7% of graduates selected the concept stage compared to 8.8% of undergraduates.

Preparation for Professional practice

Participants expressed views on whether the ID and PD courses at LDS need to improve the teaching to prepare students for professional practice. 45.6% of students either agreed or strongly agreed that the LDS teaching needed to improvement compared to 19.5% who disagreed or strongly disagreed. 34.8% of the population had a neutral opinion.

Those who thought that the teaching of DFM within the LDS needed improvement were asked to give examples of how they thought it could be improved. 40% of the student population offered a suggestion. Of this 40%, 75% expressed the need for further teaching of DFM, specifically looking at more 'real world' solutions. This included: looking at well-designed existing products and understanding how these parts were moulded and produced on a mass manufacturing scale. Multiple responses also suggested that the weighting towards visual techniques did not correspond with the amount these skills were used in industry.

Company Questionnaire

20 companies, who had previously employed LDS students as either placement students or graduate employees, completed this questionnaire.

Firstly, it was important to understand the companies' views on their respective LDS student employee's performance, before further assessing details about specific knowledge regarding DFM. The results were unanimously positive with the entire population of the survey agreeing it had been a success to employ LDS students as either placements or graduates.

Areas of Importance and Improvements

Similarly to the student questionnaire, the companies were asked to choose the four most favoured skills from a placement or graduate. The majority (94.4%) of the population of companies selected CAD as the most favoured skill. This was followed by DFM (72.2%), sketching and rendering (66.7%) and both prototyping and visual 2D presentation with 55.6% (figure 6).

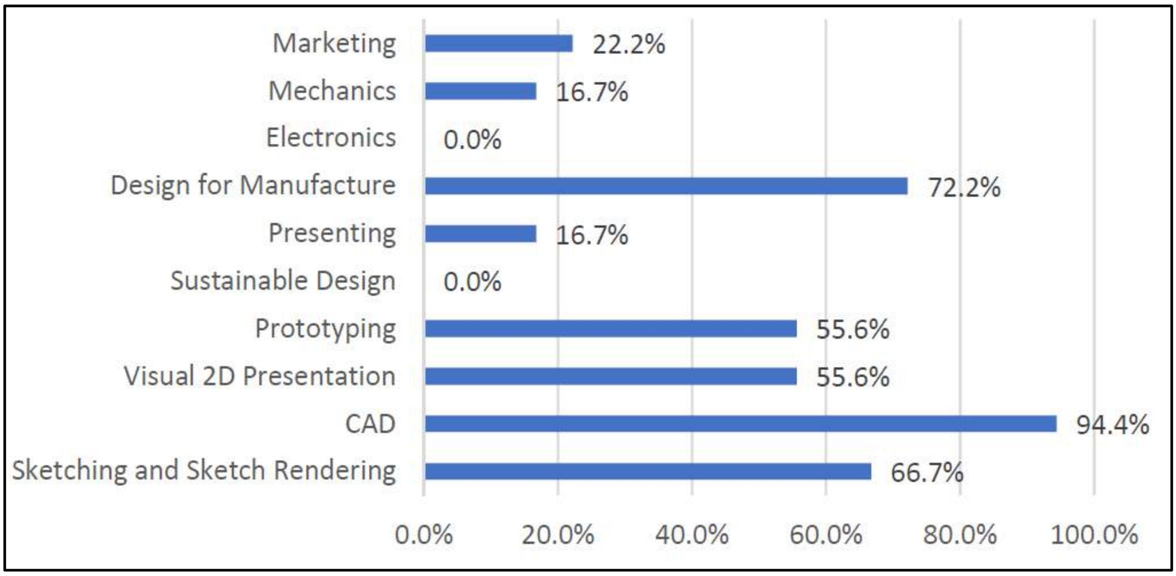

Figure 6: Companies selection of the most favoured skills from LDS students.

According to the companies, the areas that needed the most improvement were DFM and CAD with both being selected by 61.1%. The next most common answer was visual 2D presentation (38.9%) followed by prototyping (33.3%).

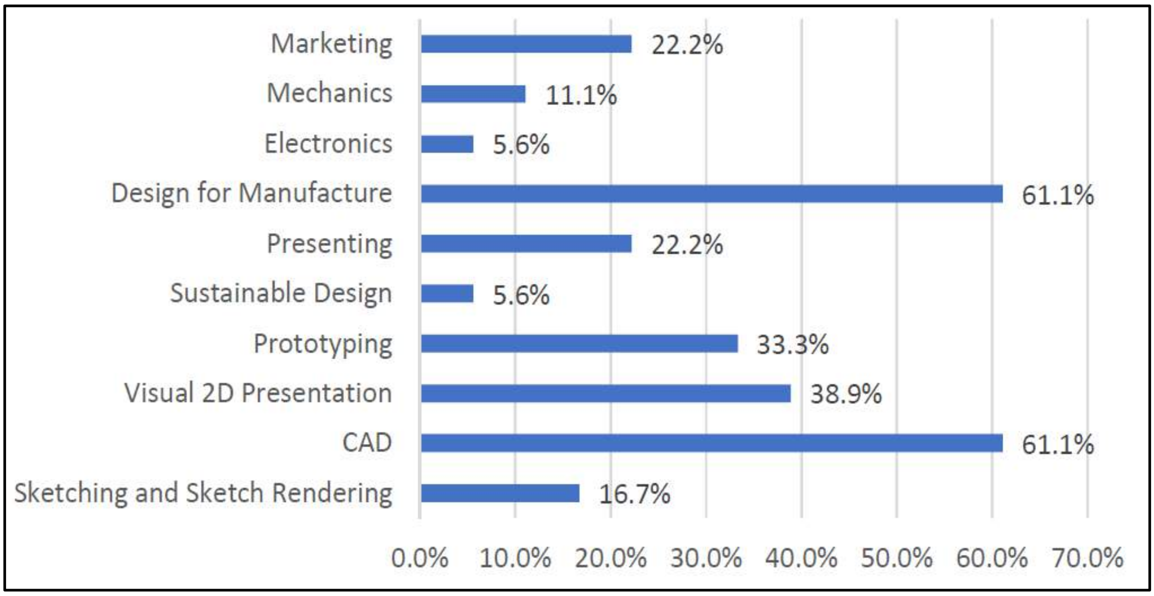

Figure 7: Areas in which companies believe that students need to improve upon.

DFM within Professional Practice

Corresponding with the student survey, the companies were asked to select when they considered DFM within their design work. Yet again, using Baxter's terms: concept design, design development, detail design, three quarters of the companies considered DFM at the concept design stage of the design process. The remaining 26.3% considered DFM at the design development stage, whilst no company selected detail design.

With regard to the which role within the company makes the biggest contribution to DFM. More than half of the participant companies selected 'in house industrial designers' as the role that makes the largest contribution to the DFM of a new product. 26.3% chose 'in house design engineers' and 10.5% outsourced their DFM needs.

Exactly half of the companies surveyed explained that they 'always' expose their placements or graduates to DFM. 38.9% claimed they often exposed their students and 11.1% 'sometimes' expose their students to DFM. None of the companies selected 'rarely' or 'never'. From this data, we can understand that 88.9% of students were exposed to some level of DFM when employed.

DFM Teaching

In relation to the companies' opinions on whether LDS students had a good general knowledge of DFM. A large number of responses (66.7%) had a neutral view, neither agreeing nor disagreeing. A small number agreed (11.1%) and similarly a small number disagreed (16.7%). Assessing whether the employee had enough knowledge to carry out their role within the company, the results were slightly more positive. Once more, a large proportion (52.6%) had a neutral opinion, however, 36.9% agreed that the students did have enough understanding for their role, whilst only 10.5% disagreed.

Building on this information, the companies were asked to point out any differences between the teaching of DFM at LDS compared to the necessary skills required within professional practice. When analysing the responses, two key themes arose: lack of knowledge of mass manufacturing techniques, and an 'understandable lack of experience'. These two themes encompassed almost all the responses, with some adding more focused suggestions, such as the need to improve knowledge of CAD and increasing understanding of cost.

Comparisons with other universities

The final quantitative question looked to compare LDS students to other university design students to understand whether there was any difference between their knowledge of DFM. The results infer that a majority think that Loughborough students are on par or have a better understanding of DFM than other universities. Only 6.7% believed that an alternative degree course produced students with better understanding of DFM.

Additional Comments

Finally, the last question allowed the companies to express any other information relating to the students' knowledge of DFM. 10 participants answered this optional question. Of these ten, seven of the companies expressed that although the designers started with a basic knowledge, in some cases suggesting it should be better, by the end of the placement the designers showed vast improvements. Another point that was raised multiple times was a distinction from PD and ID students. It was highlighted that PD students were more capable at manufacturing related tasks and, one response expressed that 'both pathways should have the same knowledge of DFM'.

Student-Company Comparisons

The following data sets directly compared the results from the student and company questionnaire to look for any similar or contrasting opinions. Figure 8 shows a very strong correlation between the students' and companies' opinions of the four most important skills of the designer. Both parties show a strong bias towards CAD, followed by DFM. Sketching and rendering was chosen as the third most important skill. Sustainable design, electronics, mechanics and marketing were not considered within the most important skills.

However, there was more disparity between the areas in which LDS teaching needs to be improved upon. The graph, figure 9, shows that 61% of companies prioritised CAD as being an area which needed improvement, whereas only 37% of students felt that CAD teaching required this development. Similarly, there was further disparity between the companies' and students' opinions of marketing and electronics. Conversely, DFM was not one of the subject areas where the students and companies differed in opinion, being selected as the most popular answer for both.

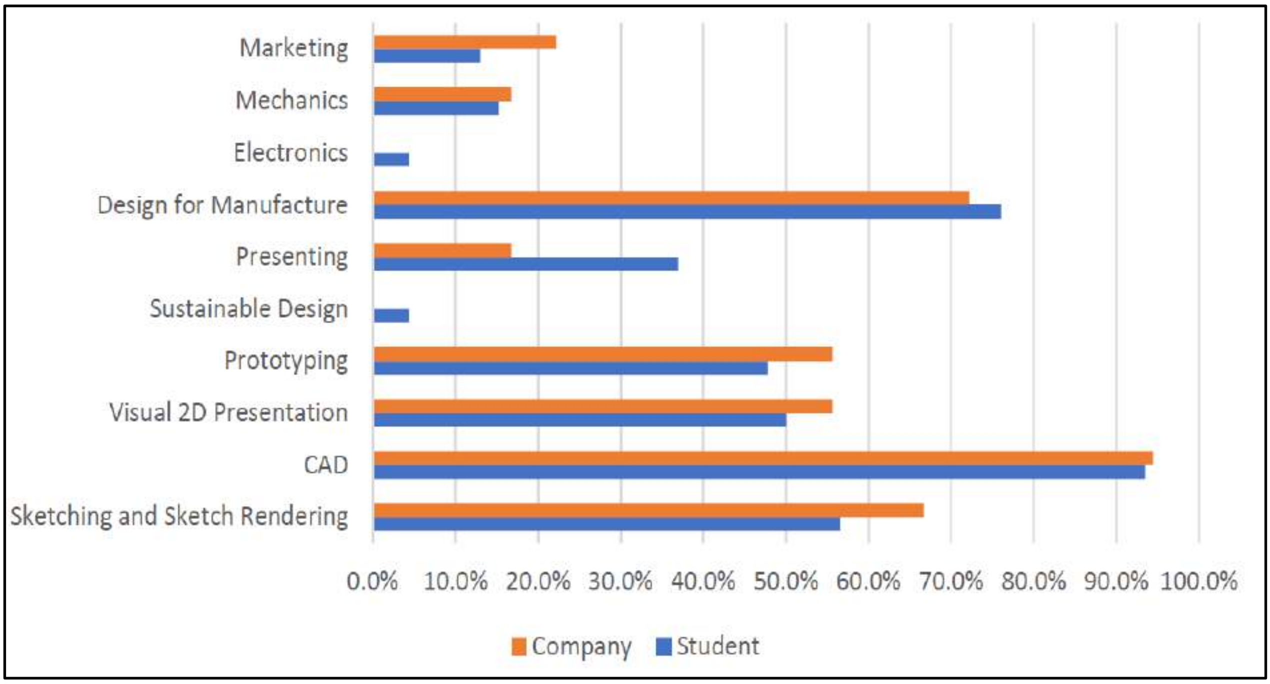

Figure 8: Comparing companies' and students' opinions on the most important skills of the designer

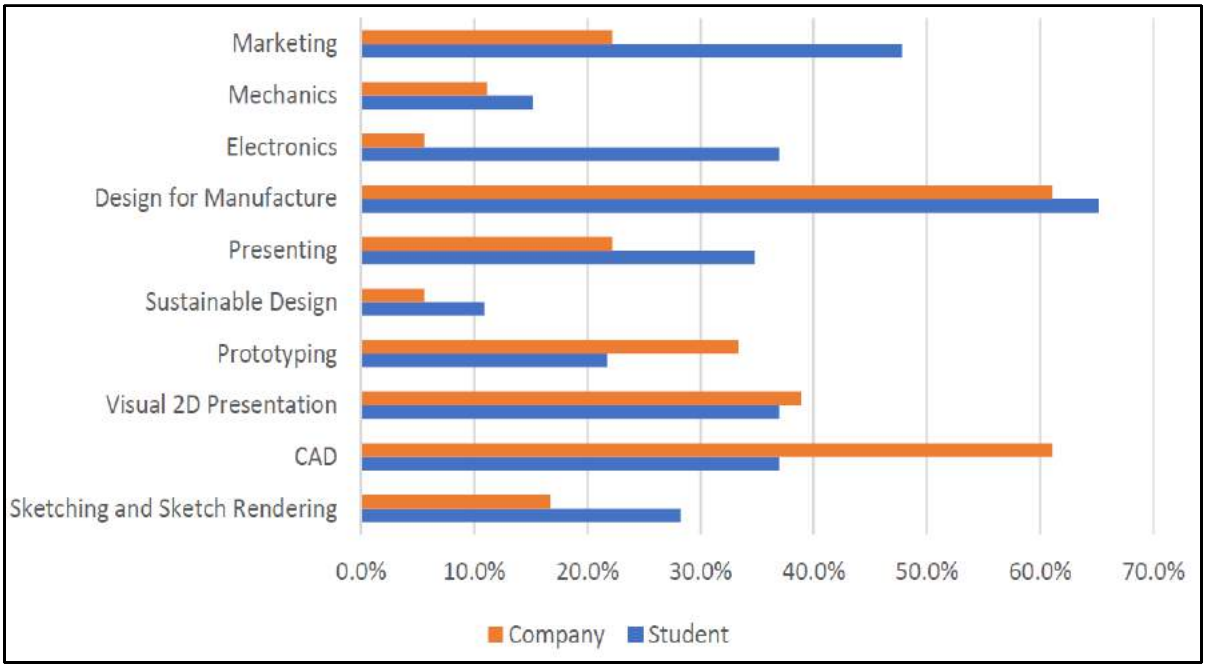

Figure 9: Comparing companies' and students' opinions towards areas of design education that need improving

When studying whether students had sufficient knowledge to carry out their role, the results between the two surveys were similar. On a scale of '1' to '5', the most popular answer from both sets was '3'. Meaning they neither agreed nor disagreed with the statement. Nevertheless, the second most frequent answer, for both parties, was that they agreed that the students had enough knowledge to fulfil their role.

Discussion

Within this research two surveys were conducted to assess the quality of DFM teaching within Loughborough Design School. The first survey was directed at both current and graduate students from LDS. The second survey was aimed at companies who had previously employed Loughborough students for either placement or graduate roles within their design teams. Initially, the surveys looked at which elements of design were most relevant to professional practice and which subject areas particularly required improvement in terms of teaching. Next, both the surveys targeted the general understanding of DFM. Lastly, both parties were asked to discuss further details and opinions about how DFM should be improved. This section will now go on to further analyse these results to determine whether the teaching of DFM at Loughborough Design School is meeting the requirements for students, allowing them to carry out their roles adequately within a professional design team.

Student Questionnaire

Within the student data sample, the number of students from the Industrial design course and product design course were almost even (47.8% ID and 52.2% PD), whereas there were a greater proportion of undergraduate responses (73.9%) compared to the 26.1% of graduate students. Of the complete student population, only 8.7% had no professional experience at all, meaning that a large majority of the respondents have been involved in both education and professional practice. This allowed them to provide comparisons between their learning and the application of DFM within industry.

The students then were asked to rate the four most relevant skills for professional design practice, before answering which area of their university teaching needed the most improvement. Interestingly, CAD (93.5%) was rated considerably more important than sketching and sketch rendering (56.5%), demonstrating how the designers have become increasingly reliant on digital techniques as suggested by Nichols (2013). DFM was the second most frequently selected option, 76.1%, signifying that students understand the importance that DFM has within professional practice.

When the students were asked to specify the subject areas that required the most improvement, DFM was selected most frequently (65.2%). When comparing this to the previous question, to identify the most important subject areas, one can see that DFM is both important and requires improvement. Therefore, it can be concluded that DFM is a key area of design in which the students believe that the education needs development.

A majority of design school students (60.9%) believe that the LDS has improved their knowledge of DFM to some extent. Out of a scale of one to five ('1' being strongly disagree and '5' being strongly agree) the mean result was '4'. However, when asking if this knowledge was enough for professional practice, the results are less positive, with a mean result of '3'. Comparing the mean results indicates that although the student's knowledge of DFM has improved, they also believe that their knowledge of DFM was not necessarily sufficient for professional practice. However, with a relatively small difference, caution must be applied to this conclusion.

Furthermore, comparing the results of PD and ID students, when asked whether they felt the teaching of DFM was sufficient for professional practice, there seemed to be a level of disparity. PD students felt their knowledge of DFM, on average, was more satisfactory than ID students. These results support Bingham et al.'s (2015) findings that the PD students are taught more in terms of engineering and therefore, it could be suggested that the ID course requires more improvement. Alternatively, it could be argued that industrial designer needs less knowledge of DFM for their role within industry. However, it is important to note that the research covered within this research does not go into detail about these specific differences between ID and PD and, therefore, further research would be needed to assess this difference.

Additionally, the participants were asked to differentiate between the taught DFM within university and the DFM applied within industry. The practical section of the DFM module, the injection moulding project, was frequently highlighted. Overall, the students felt this module was positive as an idea, echoing the results of Marshall and Page (2016). However, the extent of this success was limited due to the lack of real-world application. One graduate student stated that: 'the principles learnt for injection at university are wrong. It's teaches you exactly what you can't do in a mould tool.' A notion repeated by several participants.

Subsequently, the students were tested on their basic understanding of DFM. The results reflected positively on the teaching at Loughborough Design School, as all students grasped a basic understanding. Following this, they were asked to identify the stage at which DFM should initially be considered within the design process. This question was based on the theory outlined by Magrab (1997), that the most influential decisions on manufacturing costs are made at the concept stage. Therefore, DFM should be considered at the earliest point within the design process as costs of additional changes increases exponentially. The results showed that most participants chose the design development stage (second stage) as the preferred option (56.5%). However, when comparing undergraduates to graduates, it was apparent that graduate's results aligned themselves with the initial theory with 58.3% considering DFM within the concept stage (first stage). Similarly, when asked about the stage at which the largest manufacturing cost was determined, most undergraduates selected the design development stage again, whereas, most graduates selected the concept stage. This suggests that the taught DFM is not considering the implementation of costing and this is only realised when students have more industry experience.

Finally, the students were asked whether LDS needed to improve its teaching to prepare for professional practice and provide suggestions on specific areas of improvement. As before, the initial question asked for an answer on a scale of '1' to '5', providing a mean result of '3.6'. This suggests that slightly more students felt that the teaching needed improvement to better prepare for industry. Of those that felt improvements were needed, 75% proposed that DFM specifically needed improvement. Moreover, some felt that the heavy weighting towards visual techniques, comparatively to subjects like DFM, did not correlate within their proportional emphasis within professional practice.

Company Questionnaire

The company questionnaire targeted product design companies that employed Loughborough ID and PD students as either placement or graduate employees. This was a chance to understand if the companies thought students' knowledge of DFM was relevant and enough to participate in professional design practice. In the sample of companies, all agreed that taking on a placement or graduate from LDS has been a successful experience for the company. The unanimous result reflects positively on the overall teaching of LDS students.

To understand how much of an influence DFM had on this positive feedback, it was necessary to recognise how important DFM is within professional practice. Of the companies surveyed, 94.4% selected CAD as one of the top four most favoured skills from a design student. DFM was the second most popular answer (72.2%), whilst 66.7% selected sketching and sketch rendering. These results show a reliance on CAD, indicating professional design companies value CAD based skills more than traditional sketch based activities. These findings are in agreement with McCullagh (2010) who states that newly developing role of the designer needs less emphasis on traditional craft techniques. Furthermore, a high response rate for DFM, clearly demonstrates the importance of it within industry.

Additionally, the companies were asked to highlight subject areas that needed improvement. Both CAD and DFM stood out, with 61.1% of companies selecting these areas. On the other hand, sketching a sketch rendering received only 16.7% selection rate. These results echo earlier comments made by students suggesting that LDS puts too much emphasis on sketching techniques and more is needed in technical subject areas, such as DFM, for students to be able to better understand real-world design issues.

Next, the companies were asked about which stage during the design process they first considered DFM. 73% selected the initial concept stage as the right time to consider DFM, showing that the companies agreed with the initial theories outlined by Dewhurst & Boothroyd (2003). It can be assumed that the reason for this knowledge is due to their experience of cost implications when making changes later in the design process.

In addition to the previous question, it is known that the concept stage of new product development is a task most commonly completed by industrial/product designers (Ulrich & Eppinger, 2003). From this we can deduce that ID and PD students would make a substantial contribution to the DFM within professional practice. This theory is reinforced by the company survey, which found that 57.9% clarified 'in house industrial designers' made the biggest contribution to the DFM of a new product. From this we can conclude that the changing role of the designer requires knowledge of manufacturing and CAD, as well as more the traditional design techniques such as sketching and model making - once again echoing previous findings. These ideas are further backed up by 89.9% of the companies who disclosed that ID and PD students are 'always' or 'often' exposed to DFM when employed in a design based role.

To give further understanding of how successful the teaching of DFM is at LDS, the companies were asked to give their opinion on a scale of '1' to '5' ('1' meaning strongly disagree and '5' meaning strongly agree), if the students arrived with good knowledge of DFM when they started, and whether this knowledge was enough for their role within their company. This gave mean results of '3' and '3.3' respectively, suggesting that the companies thought that although the students' knowledge was not poor, neither was it excellent. Alternatively, this data could be interpreted as unknown, however, as previous results demonstrated, companies do believe an improvement in DFM is required.

Following this, companies were asked to state any differences they noticed between the LDS teaching of DFM and the necessary skills for DFM within professional practice. Comparable to the student responses, several companies expressed that the injection moulding project, run at LDS, did not prepare the students for mass manufacturing circumstances. They claimed that it should have: 'better links with real world situations' and students should have 'better understanding of budget restraints'. On the other hand, companies had the opinion that there would be an 'understandable lack of experience' which is best taught within industry. It is important to state that the companies used for this survey were those involved in new product development and, therefore, it would be wrong to assume that all students with placement experience would gain sufficient knowledge of DFM. Again, reiterating the need for LDS to teach DFM fully.

Moreover, companies did not think students from alternative universities had any better knowledge than those from LDS. In fact, 40% thought that students from other universities had noticeably worse knowledge, inferring that LDS's teaching of DFM is better than other courses. However, further investigation into how different design courses are run and how they teach DFM, would be needed to validate this point.

The final question gave the companies an opportunity to express any further information relating to the student's understanding of DFM. Overall, the answers concluded that although the LDS students started with a basic understanding of DFM, by the end of the placement, vast improvements were shown. From this, it could be suggested that the if all students were required to take part in professional practice, then the course's teaching of DFM would be less significant, as this would happen naturally within the student's experience in industry.

However, the majority of companies suggested that improvement of DFM teaching would be useful for the student to integrate better within the company. In addition, it cannot be guaranteed that all of the companies that employ LDS students would include DFM within their work.

Finally, an interesting point raised by more than one participant, was the distinction between ID and PD students. This suggests that PD students were more capable of completing manufacturing related tasks than ID students. One participant suggested that the same education of DFM should be apparent within both ID and PD courses. This clarifies Bingham et al.'s (2015) findings that the PD students at LDS are taught more engineering based subjects compared to the ID course. Furthermore, although the courses are taught differently, the professional roles that the students are employed within are similar. Hence, it proves that this needs to be adjusted accordingly and begs the question of whether the ID course is outdated due to the new role of the designer. More research would be needed to establish whether this is the case.

Direct Comparisons between Students and Companies

Following a comprehensive review of the student and company questionnaires individually, some of the results have been directly compared in order to conclude to what extent DFM teaching at LDS is successful at preparing students for professional practice. Initially, the first results to be compared, were the questions surrounding the key areas deemed to be most important for the role of the designer. There was a very strong correlation between results from both parties, with mutual agreement that the top four skills, in order, were: CAD, DFM, Sketching and Sketch rendering, and Visual 2D presentation. These results conclude that CAD and DFM are understood to be the most important for professional practice.

Both surveys asked the respective participants to identify the subject areas which needed the most improvement. There was more disparity between the two results when selecting subject areas such as CAD and marketing. Conversely, both parties selected DFM as the area which needed the most improvement. From this unanimous decision, it can be concluded that the teaching of DFM indisputably needs refinement.

Additionally, it was found that that the majority of companies consider DFM at the concept stage, whereas the majority of students thought that DFM shouldn't be considered until the design development stage. This difference highlights that students lack a more thorough understanding of DFM and its benefits, which are applied throughout professional practice. This is most likely because costing is not a key part of the curriculum and, therefore, possibly indicates a way in which LDS could improve their teaching of DFM. Furthermore, this result also suggests that the teaching of DFM is rarely approached early enough with the design process, which supports one student's feedback that stated: 'DFM is considered immediately in industry, whereas in the design school it appears to be an afterthought'.

Finally, the opinions of both students and companies were compared, in terms of whether they thought that LDS students had enough knowledge of DFM to carry out their profession role sufficiently. Both students and companies felt that knowledge was slightly better than average with a combined mean result of '3.6'. However, in comparison to the overall positive success of employing Loughborough students, this result is relatively poor. Therefore, combining this feedback with the newly understood importance of DFM, LDS needs to improve this area of teaching.

Conclusion

Within this research both primary and secondary research was undertaken to assess the importance of Design for Manufacture (DFM) within professional practice, comparing how it is taught within education to prepare students for industry. The research provided several interesting findings. Firstly, it was discovered that both students and companies agreed that DFM was regarded as a key skill utilised within professional practice. This was also found within the literature review, as multiple sources highlighted the benefits of DFM in relation to the role of the professional designer.

Next, it was posited by a number of sources within the literature review, that the role of the designer has evolved, changing from traditional craft based skills to more engineering based skills. These new DFM skills were identified by all the surveyed companies, stating that LDS students were ‘always’ or ‘often’ exposed to DFM whilst employed. Furthermore, a majority of companies claimed that ‘in house industrial designers’ made the largest contribution to DFM, further enhancing the importance of DFM to the newly defined role of the designer.

Having specified the new, evolving role of the designer, in which the prominence of DFM is seen as more important than craft skills, the weighting of these areas taught at LDS did not correspond to the level of importance within industry. It was highlighted that LDS students had an inadequate understanding of when DFM should be applied within the design process. This timing was found to be crucial within industry in order to remain cost effective.

Additionally, the difference between ID and PD students was highlighted by both the primary and secondary research. The results showed that ID students were taught less about engineering techniques, resulting a lesser knowledge of DFM. It can be concluded that the ID course needs the most improvement of DFM teaching, in order to better prepare students for industry. However, further studies would be needed to fully understand the differentiation between these two disciplines.

Finally, it was ultimately decided that it was successful for companies to employ LDS students. However, this positivity wasn’t reflected in the companies’ opinions about the student’s capability and understanding of DFM, yet again reiterating the need for improvement within this area. To conclude, design for manufacture is understood to be a vital for the newly defined role of the designer. Although the teaching of DFM at Loughborough Design School supplied the students with some knowledge, it does not entirely meet the requirements for professional design practice.

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Industrial Design Education as Innovation Broker through Making, Pivot Thinking, Autopoiesis and Expansive Learning

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Abstract

This article elaborates on design research in a final capstone industrial design studio unit and on the application of outcomes over eight years within a School of Engineering and its recent incarnation as School of Computing, Engineering and Mathematics. Research and curriculum innovation linked students to the new global design-driven innovation agenda as knowledge workers leading by creativity and intellectual capital. An international design studio project with a professional design agency style was embedded in the first instalment of the research. Students worked as junior designers with industry experts who couched them with a work integrated learning approach. A second instalment expanded to learning concurrent and agile development. An open program recognised students' backgrounds and experiences to create a community of learning curriculum through critical making, pivot thinking, autopoiesis and expansive learning. These contributed to also establish CDIO (conceiving, designing, implementing, operating) and STEAM (science, technology, engineering, arts, mathematics) initiatives as ways to procure evidence and facilitate production. Technology effects on design knowledge flows were addressed with participatory action research, information and communication technologies, human-computer interaction, e-manufacturing, fabrication and rapid prototyping tools. Findings indicated the need to update design education to achieve modern design artefact and knowledge construction. The greatest challenge was behavioural rather than technological. Institutional preconditioning assumed students as consumers and education as transmission skill transfer. A shift to transformative learning was possible by empowering participants to work within modern industry integrated benchmarks and achieve unique value propositions and minimum viable products that were ready to market outcomes

Key words

autopoiesis, constructionism, critical making, expansive learning, pivot thinking, transformative pedagogy

Introduction

This article elaborates on an eight-year research project in a final capstone industrial design studio unit. There was two years' preparation, three years' design research with ethics approval and another three for applications of outcomes to improve education (after a two years' interval). The article adds to another paper explaining technology within an international design studio (IDS) project attached to the unit (Author, 2010). This paper focuses on participants' behaviour, cognitive and social learning through *critical making*, *pivot thinking, autopoiesis* and *expansive learning*. Research showed new levels of meaning and knowledge construction when students became active learners and junior designers within a design agency-like environment. Historically, design education was embedded in goods-centred economies and attached to specialised niches, machineries and places of work which owned the means of production. Designers mostly executed briefs handed down from employers or clients with expertise mainly based on crafting, manufacturing and aesthetic flair. Digital technologies and globalisation progressively changed this landscape since the 1970s. New competency gaps turned innovation and productivity towards soft skills, information technology intensive industries (IT), information communication technologies (ICT), and new forms of manufacturing. Today, this shift requires graduates to satisfy market and social demands with novel forms of creative intelligence. Education has been slow in recognising students' need to transition from artisan craftsmanship and computer operation trial-error empiricism, to a knowledge workers' participatory, connected, intellectual, portable and scalable design intelligence based on science-based experimentation, simulations, decision theory and systems thinking (Friedman, 2012).

Design education intermediates between technology, society and environment by transferring technical skills to students on hard technology for manufacturing (e.g. CAD, machinery) and aesthetic appeal (e.g. sketching, modelling). A bachelor course represents intensive learning that saves years of on-the-job training. However, that intermediation does not maintain education as indispensable today. Knowledge flows are redefining design artefact and its practice. A complex intangible web of meaningful interactions among people, technology and their environment are also dematerialising design (Figure 1). There is a growing gap between design education and leading innovation benchmarks. Appropriately, this research aimed to answer the question of: *how design education can add meaningful value to students and industry, so they create new means of production and social progress through leading knowledge and design-driven innovation?* Four subsidiary questions supported this inquiry as:

1. Does typical industrial design education comply with innovation benchmarks?
2. Do students' background and institutional conditioning influence design intelligence?
3. Do student differences require customisation of learning?
4. Is it possible to transform students' attitude to learn current value proposition demands?

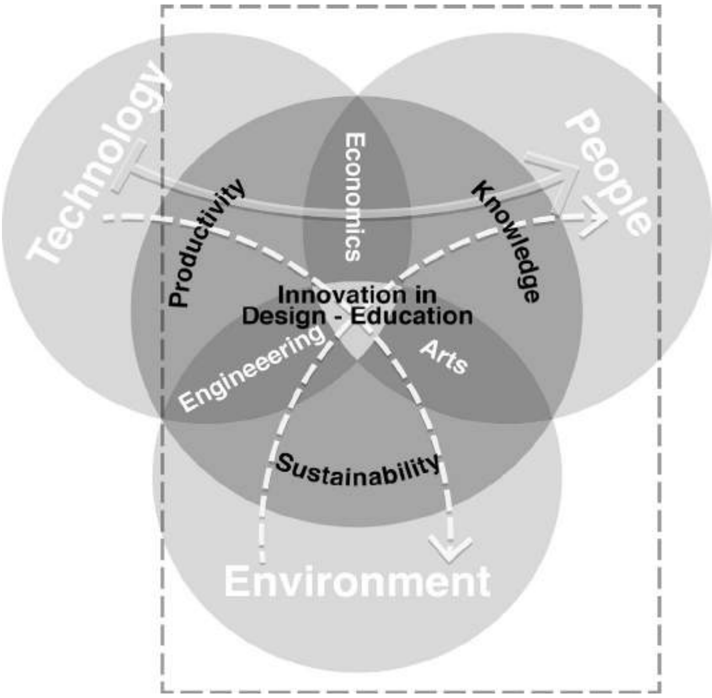


Figure 1. Environment, people and technology push-pull. Reprinted from Novoa, 2012.

Method

The project investigated design education as innovator broker based on following co-occurring processes that have individual and collective implications:

1. **Autopoiesis** (auto = self, poiesis = creation, production): Individual's ability to behave as a cognitive system that self-generate knowledge to create, produce and maintain itself in relation to others (H Maturana & Varela, 1973),
2. **Expansive learning:** Social activity that constructs new knowledge by communication, interaction and use of cultural and ethnographic artefacts, tools, symbols and language (Engeström, 2001)
3. **Pivot thinking:** Reasoning that reframes problems and move in new directions
4. **Critical making:** Hands-on process-oriented workshop framework that merges physical and conceptual exploration to discover and construct new knowledge through design artefacts

Autopoiesis

Autopoiesis, from cellular biology, is useful for explaining a student's capacity for self-creation and self-production of knowledge as an on-off interaction between a living system and its environment. This is opposite to self-reproduction that means making redundant copies (e.g. artefacts) with no information value. Traditionally, a student's environment was affected by dominant institutional and teaching models. They controlled by reproducing activities that avoided real consciousness in lethargic environments. However, design learning requires self-creation and self-production with dynamic behaviours that elicit cognition. Knowledge generation can express autopoietically like a cell (e.g. amoeba) that moves from one position to another seeking nutrition. There is a connection (known as *structural coupling*) between a cell's motor-sensory activity and its environmental stimulae before an area is exhausted and the cell goes elsewhere. A learner's conduct should be similar by self-producing efferent (Latin *efferens*: to bring or carry out) responses (behavioural, intellectual, motor and sensory) to commands triggered by external input. This cycle allows cells/learners to build internal cognitive models capable of interpreting and interacting with their environment. Movement to a new position would result from comparing actual and predicted signals and feedback mechanisms that allow forecasting new events and situations for learner's experience (Flanders, 2011; Lyon, 2004; Humberto Maturana & Varela, 1980; McGann, Ortner, & Dirks, 1991). Particularly, a learner's feedback mechanism should include social signs, reasoning, and interaction with and influence on the environment (Figure 2). Autopoietic complexity can increase the more activities cross boundaries with other systems, ranging from:

- First-order: Individual learner self-producing system values
- Second-order: Structural coupling between learners as living systems
- Third-order: Coupling between learners as organisms through distributed teams and organisations

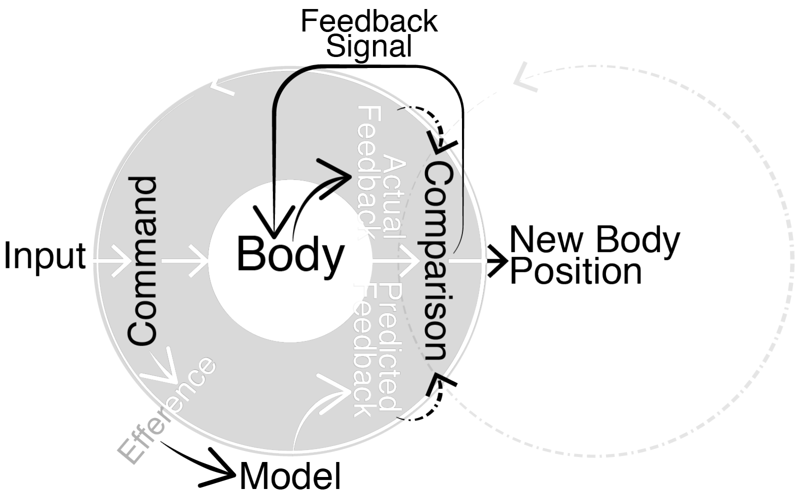


Figure 2. Autopoietic model. Adapted from Maturana & Varela(1980).

Expansive learning

Expansive learning (EL) belongs to the third-generation cultural-historical activity theory (3GCHAT). It emerged from developmental work research (DWR) in Finland that collaboratively innovated normative constrains in the workplace, technology and organisations. DWR researchers carried out active intervention through participatory action research (PAR) that enabled participants' customisation, ownership and capacity to create their own means of knowledge construction, meaning and purpose. Engeström (1995); (1999a, 1999b, 2001, 2005, 2014) proposed it when revising Vygotsky's activity theory (AT). AT broke with dual Cartesian models of society with a triad that included mediation of artefacts between humans' actions. Human psyche no longer could be understood separated from cultural means. Knowledge construction depended on individual zones of proximal development (ZPD) ranging from what is learnt independently to what cannot as it is beyond reach (Figure 3). A teacher or other student could qualify as a *more capable other* and assist in a process of individual externalisation (as act of de-automating self-reproduction) and of internalisation of learning (as act of absorption of new self-production) before progressing into a new stage (Koskinen, 2009; Mingers, 1997; Vygotsky, 1980).

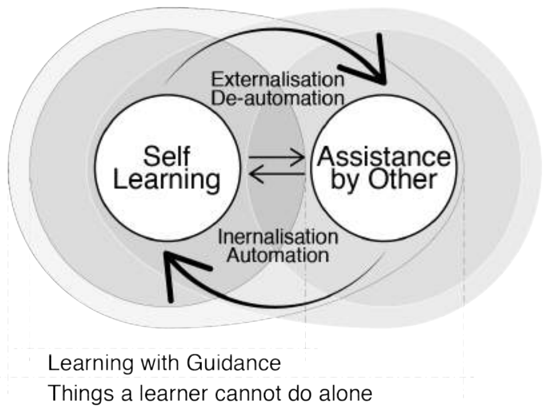


Figure 3. **ZPD model. Adapted from Vygotsky, (1980).**

EL updated AT to incorporate cultural and historical social construction of knowledge by dealing with collective and simultaneous contradictions that neither Autopoiesis nor ZPD explained. Its basic conceptual model is an activity system comprising psychological, social and institutional dimensions (community, rules, division of labour) that influences activity, subject, mediating artefacts, object and outcomes. A minimal expression of 3GCHAT contains two interacting activity systems that contribute their own community multi-voices (points of view, traditions, interests), historicity (activities over time) and contradictions (source of change, development) in the way that individual objects and outcomes produce a common new distinctive object and outcome, hopefully better than their separate contributors. Because that interaction, each participant, activity and artefact have the opportunity of radical expansive transformation through reconceptualised objects. Creativity and the making of new artefacts are the most important because of their role in producing novel social patterns and transformation of activity contents. (Figure 4).
EL comprises a four-reflective contradictions cycle process of deconstruction, reconstruction, trial and re-adjustment as follows:

1. Primary contradictions: Need state
   A. Ethnographic analysis
   B. Historical causes
   C. Revealing systemic structure contradictions
2. Secondary contradictions: Transformation
   A. Empirical and historical analysis
   B. Modelling new solution

3. Tertiary Contradictions: Resistance (with user consultation)
    A. Testing iterations of the new model
    B. Implementing new model
4. Quaternary contradictions: Realignment
    A. Reflecting on process, new model, practice, etc.
    B. Consolidating new practice
    C. Spreading it as new learning, codifying new rules, etc.

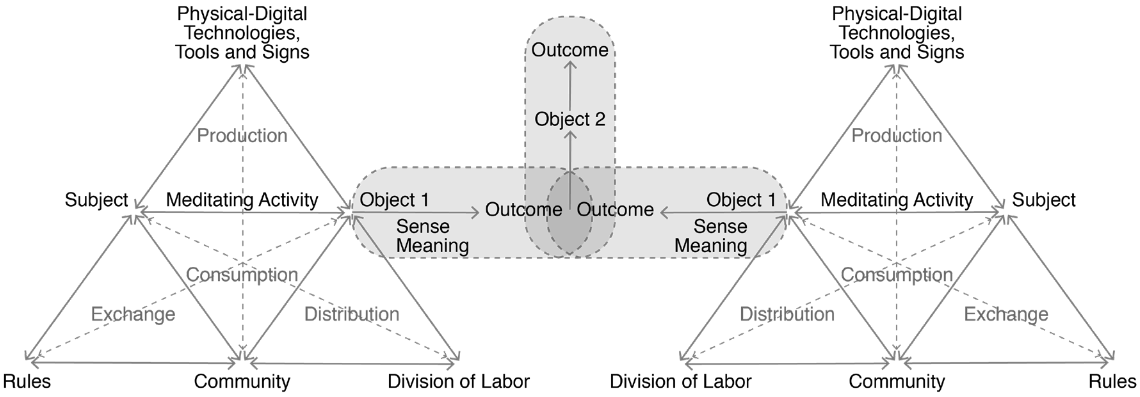


Figure 4. ***3GCHAT minimum two activity system. Adapted from Engeström, (2014).***

Pivot thinking

Pivoting among perspectives (result of data, prototypes and simulations) is essential for *critical making* that embraces modern design heuristics as an evolutionary process (i.e. experimenting, discovering, creating evidence, theorising) that helps framing problems and solutions through user contextualisation, consultation and customisation (Robinson & Pallasmaa, 2015). This requires co-production and theorising through making to articulate a new dialogue with: higher cognitive load, user culture understanding and contributions from other disciplines. Pivoting assists prominent thinkers' calls to redefine industrial design discourse, from non-transferrable craft methods and trial-error empiric skills to new, easy-to-transfer competencies that adapt methods across contexts and platforms (Buchanan, 2001; Krippendorff, 1995). Design should benefit from collaboration and scaffolding coming from more evolved disciplinary histories (Poggenpohl & Sato, 2009). Yet, it cannot be a naïve application of those disciplines as templates.

Cognitive shift needed a framework. Students were marked by legacy lacking definition of what is design innovation. Their education ranged from convergent engineering (scientific approach of facts and calculation) to divergent artistic (process often immersed in a fog of creative mystery and misconstrued as subjective aesthetic value) perspectives. By contrast, design intervention pivots non-linearly among perspectives, to investigate uncertain problems and propose diverse possible solutions (Guilford, 1967). Similar to Boden (2004); (2009), M. F. Schar, Leifer, Hinds, and Shavelson (2011), M. Schar (2015), a taxonomy for innovation would assist in eliminating the vagueness associated with traditional design education. As per Table 1, it would align with knowledge construction evolution (from conventional creativity studies onto creative industries mapping, neuro-scientific and innovation theories), and current distinctions for innovation and creativity at different levels of complexity. Disciplinary domains were proposed to build logic knowledge through forward-thinking and meaning-making based on empathy, prototyping, iterations, deduction, induction and abduction of ideas. Heuristics were to provide multiple possible, novel, internally-consistent answers to research involving user participation before narrowing down to the most plausible solution. Innovation was to be considered as either a singular expression or a mix of domains at either three cultural and conceptual complexity levels:

1. Combinational: Most common, it associates and generates relevant still unfamiliar arrangements of familiar ideas (e.g. visual collages, cartoons, heart as a pump metaphor).
2. Exploratory: Testing stylistic rules and conventions through novelty to expand them (e.g. incremental innovation, product upgrade)
3. Transformational: Quantum leap of innovation with shock impact through arresting new ideas or artefacts that dramatically redefine behaviour, conceptual space and norms (e.g. evolution theory, electricity, light bulb).

Table 1. Taxonomy for innovation as per complexity and heuristic domains

Levels of Complexity	Domain Problem Solving	Heuristic Theme	Problem Solving Tools	Outcome
Combinational	Engineering	Analyze your way forward	Equations, Analytics	Single point best answer
	Business	Optimize your way forward	Maximizing, Satisficing	Single point sufficient answers
Exploratory	Design	Build your way forward	Empathy, Prototyping, Iteration	Multiple possible novel answers
	Artistic	Feel your way forward	Qualitative, Experiential	Multiple possible balanced answers
Transformational	Research	Logic your way forward	Deduction, Induction, Abduction	Internally consistent answer

Note. Adapted from Boden (2004); (2009) Schar (2015); Schar et al. (2011)

Critical making

Critical making is a transformational approach that focuses on open and process-oriented community-based peer production. Thereby, learning becomes contextualised experience that assists the building of new socio-technical imagination and elicits analytical viewpoints on institutions, practices and norms (DiSalvo, 2009; Dunne, 2005; Dunne & Raby, 2001; Ratto et al., 2011; Ratto & Hockema, 2009). Making has departed from last century's evocative aesthetics. Then, designers' prowess was intended to increase sales by preconditioning consumer behaviour with styling. Design education was teacher-centred with closed briefs, top-down theory, hands-on and computer skills transfer. Today, globalisation and technology have shortened the distance between theory and practice to imperceptible levels. Speed of change is inverting traditional order to making and then theorising, while making is redefining relationships between people, design, manufacturing and digital technologies. Critical making becomes intelligent creation of knowledge. As per Speaks (2003), "[t]hinking and doing, design and fabrication, and prototype and final design become blurred, interactive and part of a non-linear means of innovation.” (Speaks, 2003, p. 192) Now, design value adds by defining and embracing producer-user knowledge co-production instead of accepting *fait accompli* products. Artefacts embody evolving knowledge via agile prototype iterations based on consultation, failure testing, distribution, adoption, and reconfiguration by users at different levels. Design artefacts retain currency if they stay meaningful through ease of use, users’ experience and intervention (e.g. communication, interaction, networking, re-programming) instead of brand experience, as it was before.

Results

The project focused on how to upgrade design education from old-style skill transmission to modern transformative project-based learning (PBL) over eight years. A five stages timeline evolved from:

1. Contextualisation and preparation (2005-2006) to
2. PAR/DWR benchmarking (2007-2009),
3. Stage 2 evaluation (2010-2011),
4. PAR/DWR application of lessons learnt (2012-2014),
5. Stage 4 evaluation (2015-2016).

Contextualisation and preparation (2005-2006)
Starting in 2005, the research intended to overcome educational shortcomings that made students less employable after graduation. Strategically, the unit had to:

1. Identify and fill skill gaps between education and industry expectation
2. Teach latest technology
3. Transform skills into competencies that enabled students figuring out current complexity (business, design, social, sustainability)

PBL was meant to bring together knowledge from different course streams through making (e.g. graphics, management, sciences). However, evidence showed discrepancies between pursued learning outcomes and results. When compared against approved template, students lacked “understanding of new product development” (NPD), “examination of regional and global design strategies”, “design responsibility towards users”, and “capacity to simulate and realise solutions against the background of modern complex contemporary contexts”. The unit ran for a 17-week semester with a convergent and ‘closed brief’ approach (specific requirements and outcomes to execute) directing students to craft a one model (e.g. lamp makeover) with restricted variations and some degree of aesthetics. The unit mainly comprised two stages. First, a technical package evaluation with minimal aesthetic flair ideation (six concept sketches). Second, a model fabrication complemented by 3D computer renderings of the same concept (three posters). The model had to be a polished exhibition block model (shell lacking functionality) with minor features (e.g. on-off light switch). Students worked on a few vague scrapbook-like sketches and a technical package report. A polished model and smooth 3D renderings did not add meaningful results for students. Many neither had preparation nor dexterity for hands-on modelling. Symptomatic of the course, the unit did not match our School of Engineering's STEM (science, technology, engineering, mathematics) aims towards integrated interdisciplinary learning and critical thinking within authentic contexts.

The first task for this research was breaking from transmission teaching and adjusting to a 14-week semester. Until then, students followed a sequential execution process similar to 1960s–1980s Phase Review's assembly line manufacturing (R. Cooper, 1996; 2001; 2008, 2014). The work was managed as a relay race. Tasks passed from one to the next, without commitment throughout. Accountability and iterative processes were missing. Backend micromanagement mechanisms controlled the unit, while cycles of open consultation, discussion, experimentation and discovery were neglected. Students' routines were allopoietic (allo = different, other) as they reproduced things unrelated to the self-creation needed to evolve their learning, unlike living biology. Observation, self-feedback, adjustment and self-production mechanisms were switched off (Figure 5). Consequentially, a unit makeover pilot tried to establish the following:

- Pragmatic constructionism (different to social constructivism) via collaborative learning-by-making and learning-through-playing. Essential to creativity, students independently played and pivoted by hacking, constructing and reconstructing in a tinkering process of building design as new knowledge artefacts (Harel & Papert, 1991; Papert, 1980, 1986).
- Models as series of low fidelity (Lo-Fi) to high fidelity (Hi-Fi) prototypes that expressed design heuristics and critical making, instead of just one polished block model.
- International design studio (IDS) project trial with overseas design programs used to benchmark and develop a new direction for the local course, with active participation of students, industry and government official partners.

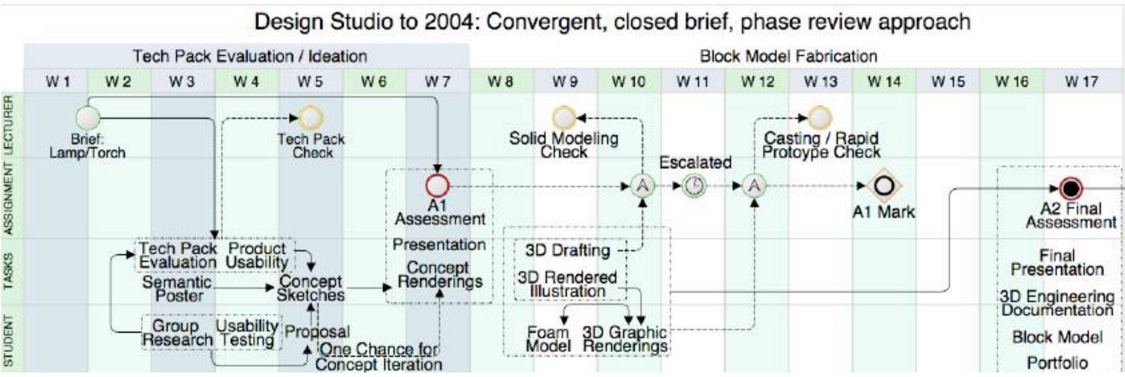


Figure 5. **Unit process flow before and after 2005. Curriculum transformation towards framework of inquiry**

PAR/DWR benchmarking (2007-2009)

The new unit invited students to work in open brief projects with an overarching theme of "learning-through-playing" and IDS with a professional design agency setup. Participants were empowered to transform their mind-sets, collaborate and resolve social systems through making, pivoting and empathy (Rouse & Rouse, 1991). Individual topics (e.g.

children toys, elderly rehabilitation, health and wellbeing) took them out of their comfort zone as projects no longer ran on assumption. Students liaised with final users to frame contradictions, areas of conflict, and to identify design problems to resolve. Practically, students learnt how to observe reality (e.g. historical, social), inquiry, identify barriers, collect data, reflect, interpret, and design through grounded experimentation and Lo-Fi to Hi-Fi prototypes used as user probes.

PAR and ethnography helped to build frameworks for activity systems that identified the natural setting of activities (the field), actors (subjects, community, institutions, tools), cognitive, cultural, environmental and social places, clusters and networks of action and meaning (mediating artefacts, division of labour, object, outcome). Contextual inquiry assisted to build workflow models to configure design research around personas, case studies, context, scenario and design iterations progressing towards a final working prototype (Beyer & Holzblatt, 1998; Crabtree, 2006; Holtzblatt, Wendell, & Wood, 2004). EL's four-reflective cycle process complemented a CDIO (Conceiving-Designing-Implementing-Operating) initiative that promoted an engineering education capable of leading the creation and operation of new products, processes, and systems. This sorted out the stresses between technical fundamentals; contextualised activity and experiential learning that enabled students to understand technology's impact on society (E. Crawley, Malmqvist, Ostlund, & Brodeur, 2007; E. F. Crawley, 2001).

Expectations changed from the previous program that accepted work as complete when it reached concept proposal only. Now, projects were final only after demonstrating a project's implementation, operation (use, adoption) and completion of CDIO/EL process. Final working prototypes proved their worth when trialled in real-life scenarios, with unique value propositions (UVP) and minimum viable products (MVP) at levels close to those of manufacturing in Asia. CDIO facilitated improvements of personal, interpersonal, system building, technical and management skills and work processes (methods, tools), while EL contributed the missing cultural, ethnographic and participatory methods critical to understand real user (student, final user) needs and the complexities of NPD team-based environments. STEM was also promoted to build technical and scientific evidence for projects.

By week 5, students' submissions comprised the entire previous curriculum for a semester. Work was presented via a Pecha Kucha pitch (20 slides in 6.5 minutes) and a report to stakeholders that rationalised user observation, consultation, context and problems framing, analysis, mental and concept visualisations, critical making, brief, Lo-Fi and block model concepts. The next nine weeks depended on peer review verdict (classmates, lecturer, industry coaches, final users). Projects with poor reviews were sent back for revision, while week 14 deadline stayed the same. Projects moved from Lo-Fi to High-Fi prototyping with partial-to-complete functionality systems and artefacts that users could interact with. Pivoting between research, iterative making and prototyping was critical for reflection and design. Students produced five-to-seven functional 3D physical models, virtual models, manual and machine-driven shaping, 3D printing, coding and human computing interaction (Figure 6).

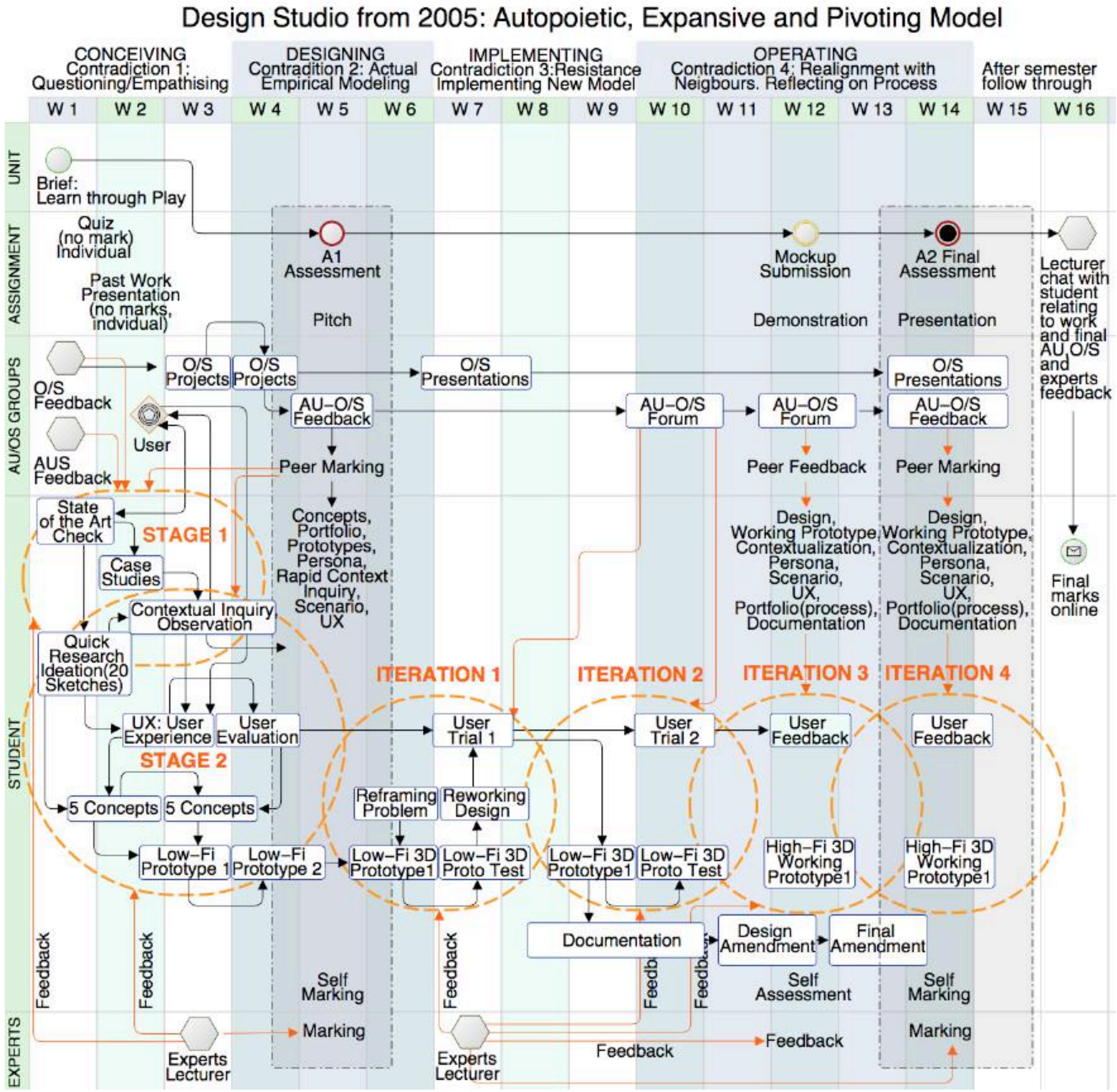


Figure 6. Unit process flow from 2005 as critical making, EL, DWR, HCD, CDIO, STEAM, UVP, MVP

Students customised innovation for their national market and others abroad. They understood users are no longer limited by geography. Participative collaboration helped students to find common issues to solve (e.g. cognitive development, obesity, aging market). MVP and UVP development benchmarks were kept as those of manufacturing and to attract financing partnerships. Quality of work, peer review, self-marking and reporting showed how students had a quick learning curve, became responsible and owned their projects from start to end. Design artefacts and projects were treated as arguments needing sound and corresponding physical, verbal, visual and written narratives. Students recorded every step through thick descriptions containing diaries, sketches, photos, and videos to explain meaningful actions and behaviour in context. Borrowing from Geertz (1972); (1973, 1993), students learnt how to structure annotations, diaries and visualisations by using a customised version of thick description. Step-by-step self and fieldwork reporting (e.g. interviews, PAR, observation, surveys) documented data, ideas, rationales, artefacts (e.g. sketches, concepts, photos, prototypes, videos) and process to explain actions, behaviour and cultural context. Narratives interpreted users' extroverted expressions, to give them meaning in:

- Semiotics terms,
- Revealing artefacts and systems "deep play" of human activity, beliefs and social discourse,
- Producing, coding (audio and video transcripts) and evaluating user events

The unit further grew onto transdisciplinary STEAM (Science, Technology, Engineering, Arts, Mathematics) championed by the Rhode Island School of Design. The 'A' denotes the arts as creativity, design, socio-cultural studies, language and liberal arts (e.g. ethics, logic, rhetoric). All provided higher-order thinking skills needed since learning and social complexity cannot be solved by science and advanced technology only (Guyotte, Sochacka, Costantino, Kellam, & Walther, 2015; Guyotte, Sochacka, Costantino, Walther, & Kellam, 2014; Maeda, 2012; Somerson & Hermano, 2013) Collective knowledge construction reformulated the unit as a self-learning organisation where students, users, industry experts and lecturer were team members (Senge, 1990). Participants peer assessed and marked each other based on evidence (e.g. research, heuristics, prototypes, user trials). They role played successively (e.g. client, designer, user, manufacturer, mentor, supplier, team member, cross group review) and formed experimentation and feedback chains for class forums (Figure 7).

This change was significant for students in relation to ICT as well. They used digital and open source tools to progress from Web 1 (instruction) to Web 2 (personalisation) and Web 3 (semantic use, knowledge creation and management). There was added complexity when international projects required synchronic and a-synchronic communication within and outside class time. Local and international participants, guest and mentors (Australia, Canada, Chile, Germany, U.S.A, Finland, Netherlands) communicated through physical, face-to-face, digital, mediated, simulated and virtual technologies. Weekly AARNet video conference lectures were held with national and international guests (industry, politics, design experts). Social networking worked as early form of product lifecycle management (PLM) and distributed e-Manufacturing. Students later shared and updated work via Blackboard, blogs and e-portfolios connected with social services (e.g. Facebook, YouTube, Delicious, Drop.io). They coded and designed digital and physical simulations with traditional hand-on tools, machinery, C++, Arduino and 3D printing (Figure 8, 9, Table 2).

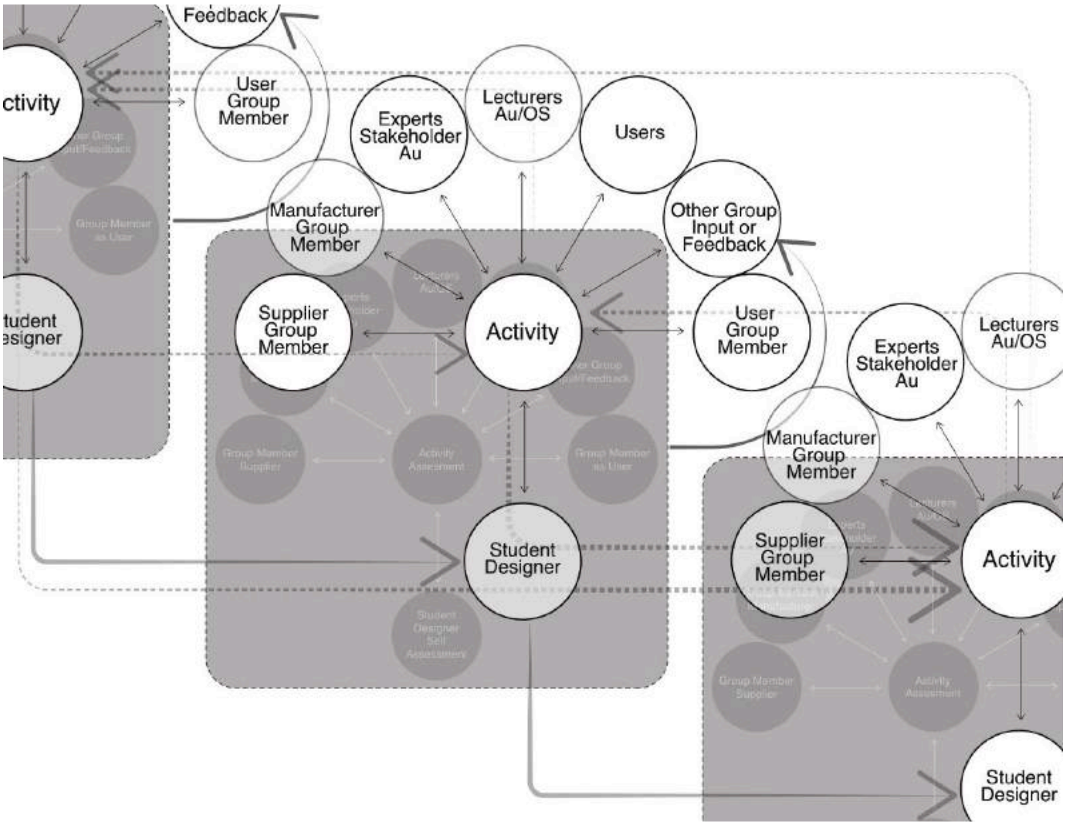


Figure 7. Participants self-learning role swapping in Australia and also with overseas from 2005

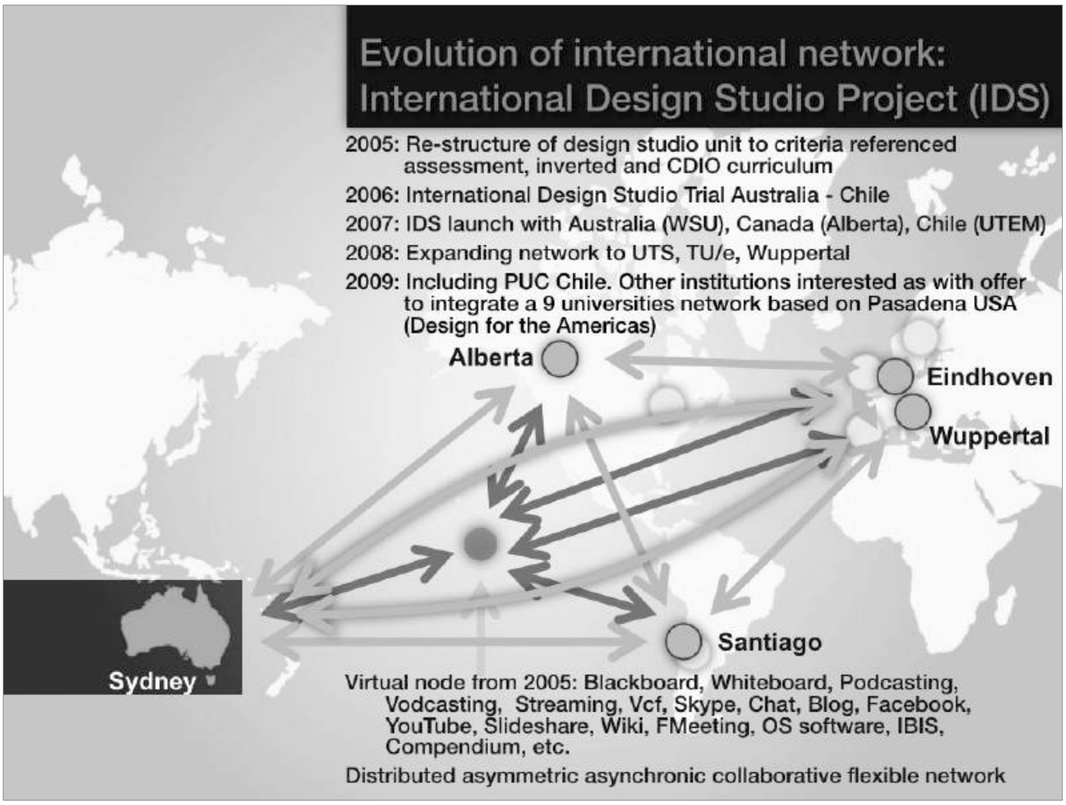


Figure 8. IDS network

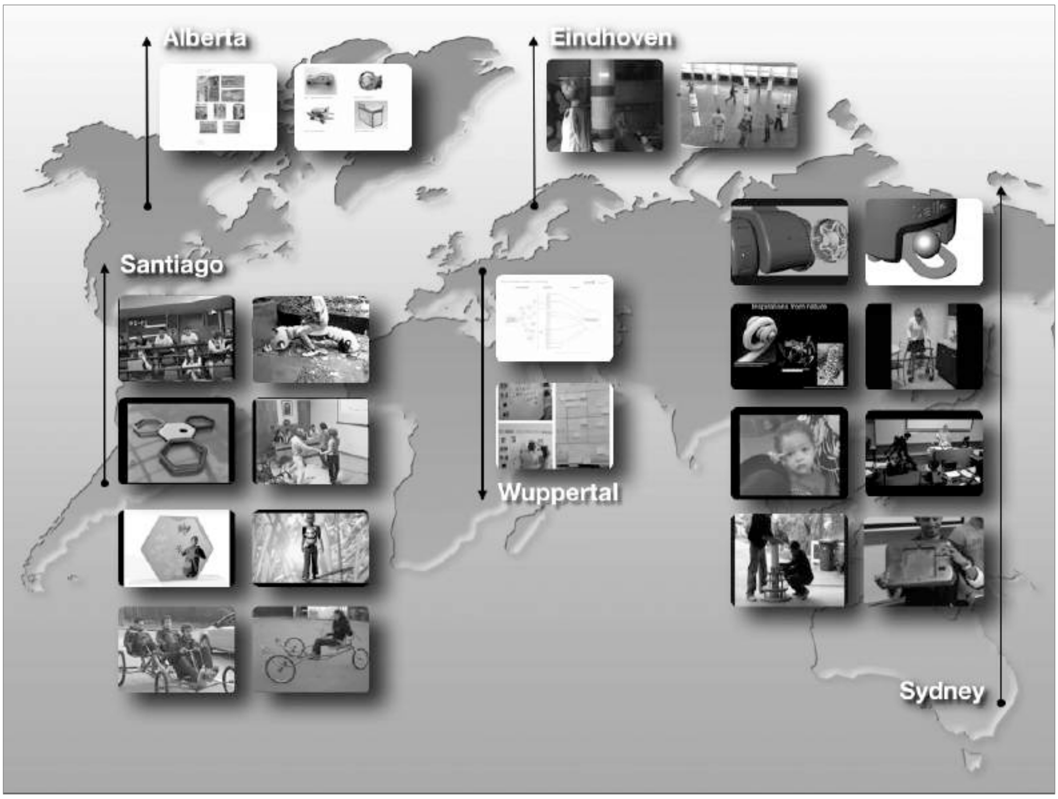


Figure 9. Students work, mentoring and examples

Stage 2 evaluation (2010-2011)

Stage 3 evaluated students' learning dynamics and outcomes for the period 2007-2009. However, PAR/DWR was suspended for this period. The course turned to a conservative mode of delivery that had worked for decades. This was seen as a natural reaction to disturbance of the status quo. Work and benchmarking disrupted the local traditional transmission teaching model. Still, data gathered had to be checked for relevance, so that lessons could be applied modularly and transferred to other cases for future opportunities. This research was based on the argument that the industrial design industry, its market, stakeholders and users have changed since the start of our 21st century. Globalisation and technology diffusion have broken conventional divides among disciplines, geography, hard and soft technology and production. In Australia, traditional-trained industrial design and its employment have dropped in the last three decades because they depend greatly on hard technology. Importantly, production has moved to nearby Asian countries at a cheaper cost and increasing quality. These countries are already moving into the creative domains of NPD and innovation. Hence, design education needs to embrace that change with new forms of collaboration, communication, learning, production and work.

Over five years, the project transformed the capstone unit from an industrial age teacher-centred approach to a 21st century inverted curriculum with student/user-centred and agile development focus. Participants critically made design statements through prototyping and user participation with unique problem framing, solving and new elucidations. They moved quickly through making, theorising and formulating new knowledge with iterative visualisation and testing. Inquiry, conceptualisation and design progressed in cycles from Lo-Fi to Hi-Fi prototypes. As per Egger (2000), Lo-Fi was a low-tech and low cost remedy for tunnel visions. Purposely, students were discouraged from beginning with technical specification and high-resolution modelling. Instead, they explored mental and conceptual modelling of human-centred design (HCD) alternatives following observation, consultation and experimentation. Regardless of individual backgrounds, experience and skill, participants became comfortable with using a mix of post-it notes, paper, cardboard and foam block models, building and enacting scenarios. Then, they easily translated learning into high-level Hi-Fi physical and digital artefacts to meet and test user needs.

Table 2 Technologies used in the project

	Traditional Technology skill sets: Physical – Face to Face				
	2005	2006	2007	2008	2009
	STEM		STEAM		
	Project Management: i.e. Mind/concept swim lanes, mapping, planning, agendas, meetings, worksheets, Gantt charts, minutes				
	Research: Design heuristics, design thinking, human-centered design, action language, participatory, observation, quantitative and qualitative, combinational, exploratory, transformational, thick description and ethnographic, etc.				
	Drawing skills: E.g. Conceptualizing, mapping, sketching, renderings, hand-drawing line and painted illustrations				
	Prototyping: E.g. Paper, block, working models, handcrafting, fiberglass, silicone, foam, wood, metal, vacuum forming, etc.				
	Presentation Skills: E.g. Felt and acrylic renderings, watercolor, pen, pencil, gouache, etc.				
	New Technology skill sets: Digital – Simulation, Virtual				
Web	Web 1: Instruction	Web 2 : Personalization		Web 3: Semantic – KM and Creation	
	2005	2006	2007	2008	2009
			Student exchange		Chilean student exchange
3D CAD	3D CAD Parametric for Manufacturing: SolidEdge, SolidWorks ☐ 2D output (working, control and specification drawings) ☐ 3D Parts and assembly and STL output 3D CAD Polygon for Visualization (i.e. Rhino, 3D Max, VRay, Blender) 3D Rapid Prototyping: Additive StereoLithoGraphy (SLA), Fused Deposition Modeling (FDM), Stratasys, Object, Magic, STL / IGES, etc.				
Blended Learning	Blackboard vUWS (Assignments, Lectures, Podcasting, Discussion Board, etc.) Podcasting and Vodcasting (Participants recordings and broadcasting) Chat / MSN Messenger				
Project Management	**Mind/concept mapping software: MindMap, FreeMind, NovaMind, etc.** **Management software: MsProject, OpenProject, GanttProject, etc.** **Flexible and Distributed Manufacturing:** **☐ Product Lifecycle and Data Management (PLM, PDM),** **☐ Introduction to Advanced Device Management (ADM)**				
Mediated Comms		Video Conferencing (AARNet3) Virtual weekly classroom across the Pacific Skype, iChat, MSN Messenger Live			
Design		Coding, Programming Website Design Blogs			
Social Networking			**Delicious (web pages and bookmarks sharing)** **Facebook (lecturers and students exchange, online unit curriculum)** **ooVoo (video chat)** **Slideshare, You Tube, Wikis**		
Knowledge Management				Dropio (academic exchange) Semantic web (ontologies) OS broadcasting (i.e. FMeetings) OS Issue-Based Information System - IBIS: Compendium (information, ideas, arguments), VUE (integration of digital resources), XMind (project, knowledge management) EndNote, RefWorks Reference Finder, Treemaker	
Knowledge Management					**OS broadcasting** **OS KM (i.e. Compendium server based)** **Second Life (storing and exchange)**

Note. Reprinted from Novoa, 2010.

Students' thick descriptions and self-assessments helped to further understand factors that the official university qualitative surveys, called Student Feedback on Units (SFUs), did not cover. Three examples show the virtues of customising projects to stakeholders and final users. A South Sudanese refugee student had difficulty integrating technical skills and practice meaningfully (e.g. high-resolution 3D printing), in contrast with other students from stable families settled for generations in Australia. PAR/DWR triggered learning when he matched his experience, skills, and interests with user needs relating to the reconstruction of his home country, that was to gain independence in 2011. His work influenced his decision to go back and assist with developing educational resources for literacy (English, Dinka, Nuer, etc.), numeracy and STEAM. His approach was based on bottom-up community participation and training, basic industrialisation of raw, recycled and upcycled local resources, open source distribution and sharing of design plans and instruction (Figure 10).

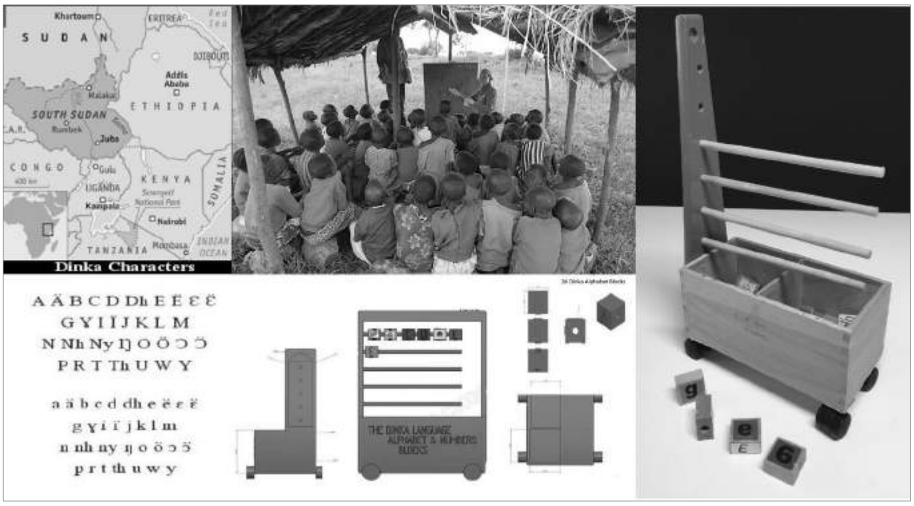


Figure 10. South Sudan design for development (D4D) project for community reconstruction

Numerous students also focused on external competency benchmarks instead of internal pass-mark goals. Several stated willingly they 'did not reach the expectations and standards that all the others have done' These students asked for a fail mark and re-enrolment while 'looking forward to the next year's' unit again. They persisted even after an extension for submission was offered. They thought they had not upheld standards and said it would be unfair on the rest of the class to be given an extension for submission as that did not align with industry framework on deadlines. School management noted such a display of student ethics occurred for the first time in the University's records.

At the other end, several students obtained jobs after presenting their capstone unit work. Others received contract offers for commercialisation. Among them, a high-tech engineering arms industry recruit shared:

> "you have brought a business sense to me and other students, something that has been sorely forgotten. I would especially like to thank you for pushing me in your design studio unit, this produced fantastic results and really challenged not only myself, but the others in my group to produce a production ready concept for market. The end result was a contributing factor to my successful job interview with

the defence industry beating mechanical engineers with more experience for the placement."

Students' outcomes merited consecutive invitations to exhibit publicly in Sydney CBD's historic Customs House. Reviews noted their quality rivalled graduating fourth-year Honours projects. There were 96 thank-you letters received after the unit and graduation following the 2007-2009 research phase. Many participants noted they completely understood the learning shift promoted in the unit once they were working in the industry. Subsequently, the University conferred the project with a 2012 University Citation Award for Outstanding Contributions to Students Learning. (Figure 11).

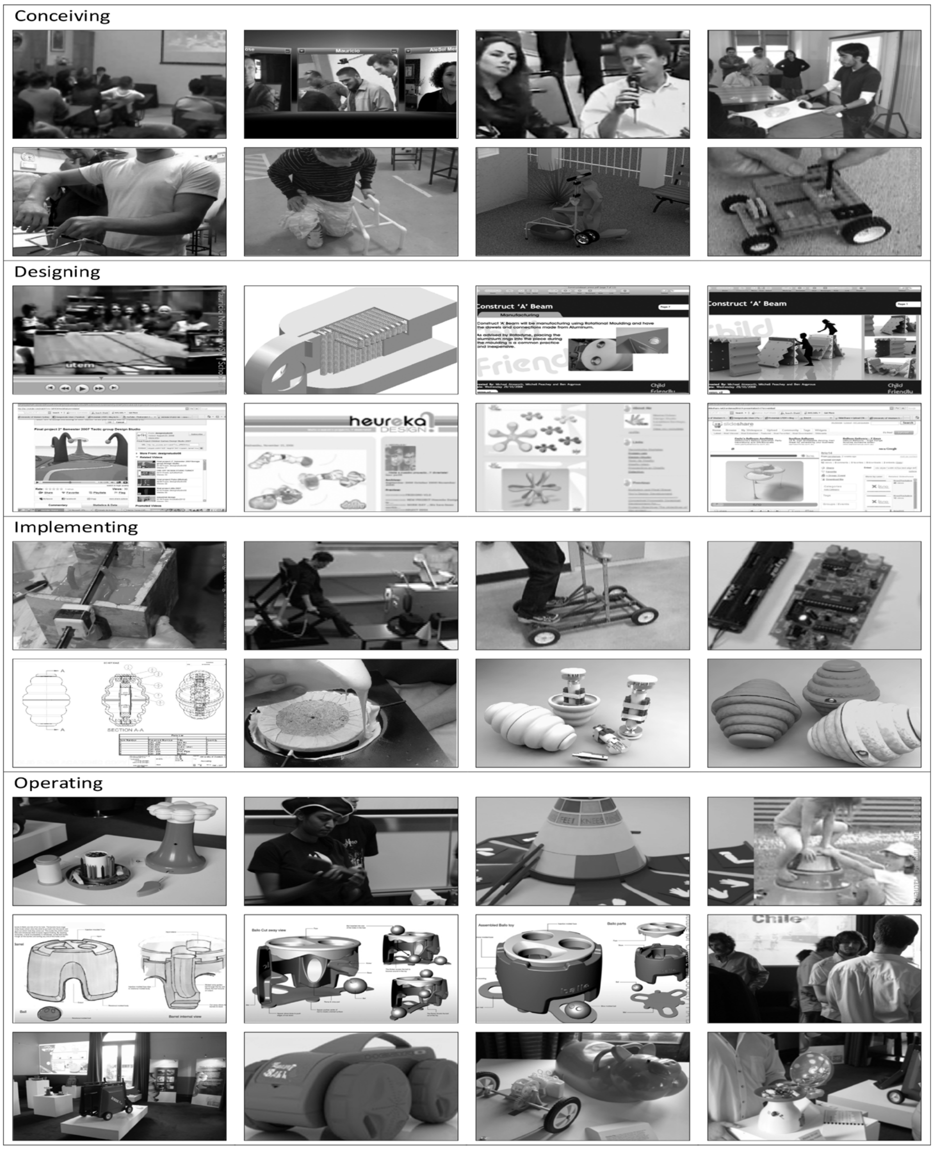


Figure 11. Participants' CDIO/EL process

The PAR/DWR approach found deeper learning issues than official measurements could uncover. 25 volunteers participated as case studies each time for over three years from a total of 119 students plus others from low socio-economic status (Low-SES) who attended free of charge. Qualitative analysis was based on students' comments, feedback, participation, recommendations and work (visual, written, verbal, thick descriptions, etc.).

Importantly as pre-project diagnosis, students were asked to fill a quiz and show what they considered their previous best and worst work at the beginning of the semester. They then answered a post-project quiz and offered comments. Two forms of qualitative assessments were chosen to understand data gathered. Multidimensional parallel coordinates helped in assessing complex sets of information among participants as directional trends that had no typical natural order in traditional teaching. Those visualisations would prove customised DWR viability beyond assessment marks despite participants' backgrounds, experiences, socio-economic status, provenance and geographies for education and upbringing. ANOVAs (analysis of variance) were also used to assess whether there were potential statistical variations and significant differences among participants' work in the same period and over three years. Plotted observations would show how reliable the applied methods were, while taking into account potential year-to-year changes (e.g. different cohort, infrastructure, regulation, technical and workshop support).

30-dimensional variables were plotted into a multidimensional parallel coordinates' visualisation. Among them, 27 distinctive variables that comprised students' quizzes, assignment components (e.g. research, concepts, development, modelling, testing), and students' descriptions and assessments (self-inspection, individual, allocated group, cross group review) were measured binarily in reference to three main factors:

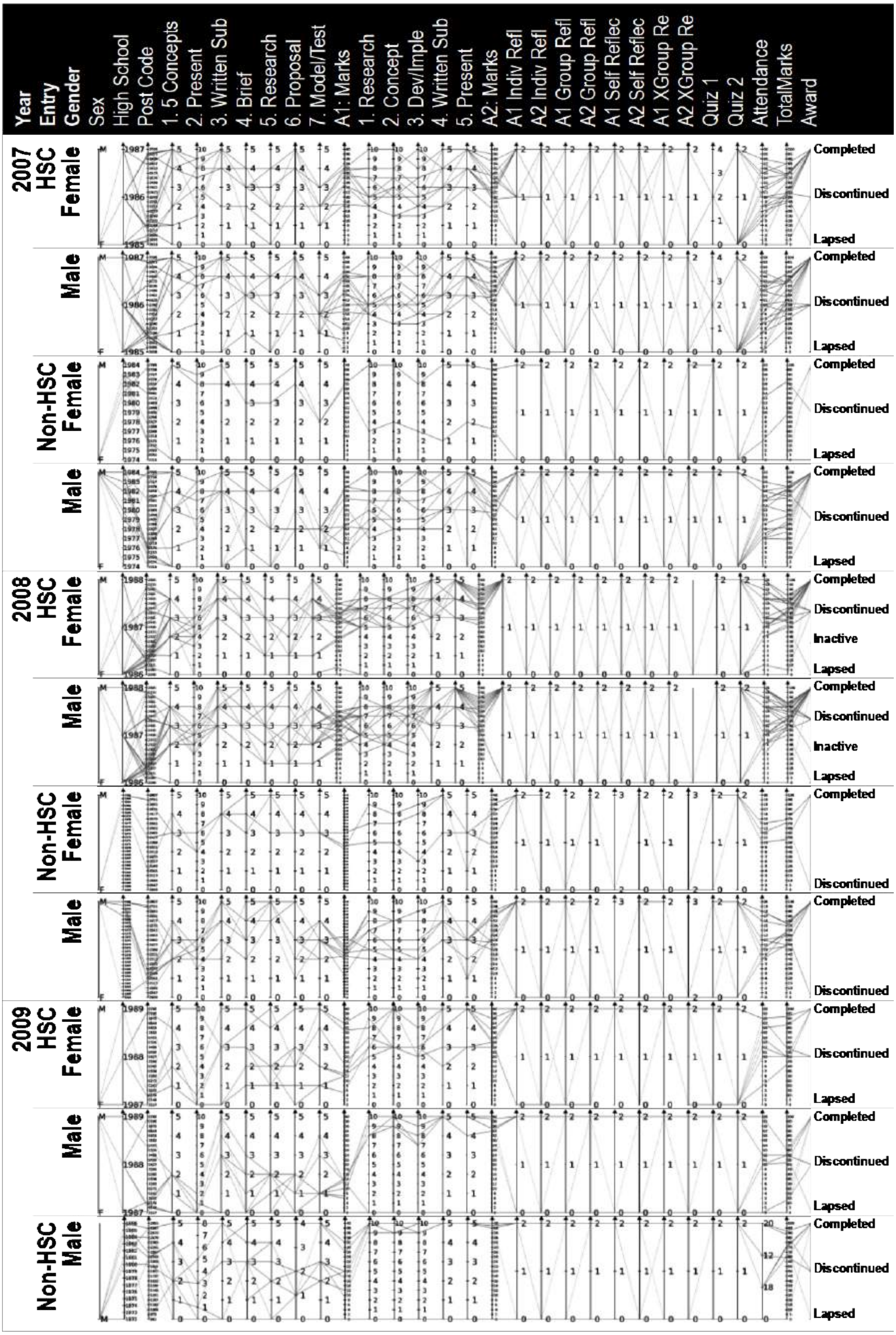
Age: That divided direct-entry students to the course who were school leavers with high-school certificate (HSC) and non-direct entry who were mature students (Non-HSC)

Gender: To distinguish differences in learning modes

Postcode: This was used as indication of background, economic status and provenance, as per demographic statistics.

Plotting and scaling showed similar linear correlation on order and rotation among age and gender. Blushing demonstrated that females achieved proportionally higher than males in tasks relating to contextualisation and data analysis. Meanwhile, males moved up quicker and scored higher than women in relation to research by making, development and modelling. Visualisation supported PAR observations that women performed well in networking and detailing while males did with manual work. The latter were less engaged and communicative than the former at the start of the unit. Although all improved progressively, initial negative (inverse) correlations relating to teamwork collaboration confirmed doubts that students were trained for it when they reached senior year. Non-HSC participants had higher retention, completion rate and achieved better marks than HSC participants proportionally. Postcodes indicated that students came mainly from three areas characterised by middle-class blue-collar population with a high multicultural mix (Asian, European-Mediterranean, Middle-East, Latin American). Still, location did not precondition individual outcome. Private or public schooling did not show significant difference relating to critical thinking, 2D and 3D visualisation, method and process of design. Those abilities and STEM literacies were below standard at the start of the unit. However, writing skills were stronger in students coming from private school. Regardless of age, gender, postcode and SFU results, plotted observations moved upwards over time towards positive relationships in the unit (Table 3).

Table 3. 2007-2009 Multidimensional parallel coordinates for HSC and Non-HSC.



Two factor ANOVAs were applied to participants' work to see whether plotted observations indicated significant reliability. Three null hypotheses were prepared to test:

1. No difference between students' traditional teaching (evidenced through part of assessment 1) and new learning methods (demonstrated with assessment 2)
2. No difference among assignments over a three-year period
3. No interaction effect among dependent over independent variables in the tests

ANOVAs presented students' marks as attribute independent variables (rows) in relation to two practical assignments representing dependent variables (columns) presumed as results of the manipulation of independent variables. Significance was to be demonstrated by a P-value of less than 0.05 threshold (95% level of confidence probability) and whether the F-value (variance of a group means among groups) was larger than the F-critical (boundary between significance and non-significance).

The first three ANOVAs without replication (Tables 4, 5, 6) for individual years showed the new teaching approach influenced unit learning in the last two years but had no significance in 2007. Conversely, 2007 and 2008 showed significant individual improvements while 2009 did not. Some correlation was seen with SFU Likert results (shown further). A last ANOVA with replication (Table 7) assessed the three years longitudinally and led to recommend to:

- Reject the first null hypothesis and support the alternative
- Accept the second null hypothesis that validates methods longitudinal consistency
- Reject the third null hypothesis and validate interaction effect and influence of dependent variables (assignments) over independent variables (students).

PAR/DWR application of lessons learnt (2012-2014)

This research restarted after a two-year hiatus while another academic delivered the unit on traditional mode. The opportunity came about when statistics showed the standard transmission model for education was insufficient (e.g. student attrition at 50%, negative student satisfaction surveys for the course). A vision for a student-centred, industry and socially integrated curriculum was proposed. The 2005-2009 research period on this capstone unit served as proof of concept for course makeover. The 2012-2014 stage would pursue to achieve reliability, consistency of measure, and outcomes that could be transferred to other circumstances.

New students to the unit said they knew about this capstone's high expectations since starting their degree. They welcomed the opportunity to work in this PAR/DWR phase. However, they also felt challenged by its standards. This time, digital and ICT tools were upgraded. The course was supported with new computing and collaborative learning spaces, workshop, 3D rapid prototyping lab (25 low-to-high resolution units), and an e-portfolio Pebble+ (Blackboard complimentary) grant that simplified the many ways students developed projects online and social networking. This instalment kept the model as before while taking further steps to enhance the design of NPD work with:

- Scaffolding of three assessments that fed and overlapped each other with a concurrent engineering process
- Agile development based on participants collaboration and critical making
- Work integrated learning (WIL) of real life projects supported by industry coach-experts
- Benchmarking to prove outcomes' consistency and validity outside the University and within industry and the public

Each assessment fit complete CDIO/EL's four-reflective contradictions cycles every four weeks. Assessments complexity increased to a level equivalent to junior/mid weight designer in the industry. Learning-by-making and learning-through-playing empowered students to own their projects and develop associative, concurrent, multi-layered, multi-literate and deep learning. Brief releases started with:

- Week 1 "Assignment 1: Rapid Contextualisation (Closed Brief)" intended to quickly form a collaborative community that produced from Lo-Fi prototypes to operational proof of concepts. The fast pace of work pushed students to abandon passive habits acquired with transmission teaching. They experimented, built, tested, rode and raced against each other a cardboard 1:1 scale vehicle in three weeks. Then, they did a post-mortem, amended projects, did further testing and marked themselves in reference to other students and international benchmarks.

Table 4. 2007 ANOVA Two Factor Without Replication

Anova:'Two'Factor'Without'Replication

2007 SUMMARY

Student'No	Count	Sum	Average	Variance
2	2	68	34	2
3	2	68	34	0
5	2	70	35	18
8	2	67	33.5	4.5
12	2	68	34	0
15	2	42	21	32
16	2	37	18.5	4.5
20	2	44	22	162
21	2	68	34	0
22	2	67	33.5	4.5
25	2	60	30	2
28	2	57	28.5	24.5
30	2	70	35	18
36	2	67	33.5	4.5
39	2	67	33.5	4.5
41	2	70	35	18
44	2	30	15	200
45	2	37	18.5	4.5
47	2	70	35	18
49	2	70	35	18
54	2	57	28.5	24.5
56	2	68	34	0
61	2	38	19	8
64	2	37	18.5	4.5
67	2	70	35	18
Assessment'1	25	705	28.2	63
Assesment'2	25	762	30.48	55.76

ANOVA

rce'of'Variati	SS	df	MS	F	P8value	F'crit
Rows	2320.72	24	96.6966667	4.38268621	0.00029299	1.98375957
Columns	64.98	1	64.98	2.94515788	0.09901781	4.25967727
Error	529.52	24	22.0633333			
Total	2915.22	49				

Table 5. 2008 ANOVA Two Factor Without Replication

Anova:'Two'Factor'Without'Replication

2008 SUMMARY

Student'No	Count	Sum	Average	Variance
4	2	60	30	8
7	2	59	29.5	84.5
8	2	59	29.5	84.5
9	2	58	29	98
11	2	59	29.5	24.5
12	2	59	29.5	40.5
13	2	60	30	72
14	2	43	21.5	12.5
16	2	3	1.5	4.5
19	2	56	28	0
21	2	64	32	18
27	2	42	21	72
32	2	59	29.5	60.5
38	2	57	28.5	4.5
42	2	62	31	2
43	2	60	30	0
44	2	60	30	0
45	2	62	31	2
46	2	63	31.5	4.5
47	2	64	32	8
48	2	62	31	2
49	2	64	32	8
51	2	45	22.5	4.5
52	2	46	23	8
54	2	62	31	2
Assessment'1	25	640	25.6	35.8333333
Assesment'2	25	748	29.92	61.4933333

ANOVA

Source'of'Variati	SS	df	MS	F	P8value	F'crit
Rows	1944.12	24	81.005	4.96303482	0.00010643	1.98375957
Columns	233.28	1	233.28	14.292658	0.00091563	4.25967727
Error	391.72	24	16.3216667			
Total	2569.12	49				

Table 6. 2009 ANOVA Two Factor Without Replication

Anova:'Two'Factor'Without'Replication

2008 SUMMARY

Student'No	Count	Sum	Average	Variance
4	2	60	30	8
7	2	59	29.5	84.5
8	2	59	29.5	84.5
9	2	58	29	98
11	2	59	29.5	24.5
12	2	59	29.5	40.5
13	2	60	30	72
14	2	43	21.5	12.5
16	2	3	1.5	4.5
19	2	56	28	0
21	2	64	32	18
27	2	42	21	72
32	2	59	29.5	60.5
38	2	57	28.5	4.5
42	2	62	31	2
43	2	60	30	0
44	2	60	30	0
45	2	62	31	2
46	2	63	31.5	4.5
47	2	64	32	8
48	2	62	31	2
49	2	64	32	8
51	2	45	22.5	4.5
52	2	46	23	8
54	2	62	31	2
Assessment'1	25	640	25.6	35.8333333
Assesment'2	25	748	29.92	61.4933333

ANOVA

Source'of'Variati	SS	df	MS	F	P'value	F'crit
Rows	1944.12	24	81.005	4.96303482	0.00010643	1.98375957
Columns	233.28	1	233.28	14.292658	0.00091563	4.25967727
Error	391.72	24	16.3216667			
Total	2569.12	49				

Table 7. 2007-2009 Assessments 1 and 2 ANOVA Two Factor with Replication

Anova: Two-Factor With Replication

SUMMARY	Assessment 1	Assesment 2	Assessment 3	Total
2007				
Count	25	25	25	75
Sum	705	762	298	1765
Average	28.2	30.48	11.92	23.5333333
Variance	63	55.76	18.41	113.711712
2008				
Count	25	25	25	75
Sum	640	748	374	1762
Average	25.6	29.92	14.96	23.4933333
Variance	35.8333333	61.4933333	23.04	79.0911712
2009				
Count	25	25	25	75
Sum	448	766	1561	2775
Average	17.92	30.64	62.44	37
Variance	180.326667	158.906667	4472.34	1915.81081
Total				
Count	75	75	75	
Sum	1793	2276	2233	
Average	23.9066667	30.3466667	29.7733333	
Variance	109.842523	89.661982	2006.25874	

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	9094.56889	2	4547.28444	8.07351981	0.00041551	3.03766731
Columns	1905.50222	2	952.751111	1.6915711	0.18666111	3.03766731
Interaction	32473.2711	4	8118.31778	14.4137452	1.9001E-10	2.41344398
Within	121658.64	216	563.234444			
Total	165131.982	224				

- Week 3 “Assignment 2: Industrial Device (Semi Open Brief)” release of Lo-Fi to Hi-Fi design, implementation and operation with five WIL industry coaches’ WIL.
- Week 4 Assignment 1 presentation and marking overlapped with “Assignment 3 Open Brief” major assessment release where students applied the learning gained to date with a full CDIO/EL resolution.
- Week 8 Assignment 2 presentation, collective and individual self-assessment.
- Week 14 Assignment 3 presentation with a chance to present revisions of previous assessments.

Similar to the 2007-2009 PAR/DWR stage, students were able to compress traditional semester models into four weeks. That realisation helped setting up concurrent NPD processes that simulated design work in the industry. Again, students said they had worked more in this unit than in any other in the course before. They commented the faster pace CDIO/EL cycles became an effective trigger for learning, critical making and design. Their self-esteem was boosted when invited to participate on national competitions. With no precedent in the course history, students won commendations, second and first awards over three years in events dominated by other prestige and better financed universities. Awarded students earned a one-year internship and mentoring with the industry. Their projects were taken further into commercialisation (Cormack, 2013 - 2015). These awards resulted from one assessment of four weeks in the unit. This was in contrast to other universities' entries, where the whole semester was dedicated to this students' competition project.

Stage 4 evaluation (2015-2016)

This final evaluation checked on PAR/DWR stage 4 findings in relation to PAR/DWR stage 2 to confirm consistency and reliability. The former comprised international students' participation to lesser degree than the latter. However, its main focus was to benchmark against institutional and industry standards locally. A 2012-2014 revision of students' written comments, notes and 112 outcomes (as a sum of three assessments per year over three years), showed similar to Stage 2 when handling large variables of qualitative data (e.g. multidimensional parallel coordinates, ANOVAs). Outcomes demonstrated a quick shift in students experience from transmission teaching to transformational learning can be possible and benefits them.
Official data and qualitative surveys supported this research's aims and outcomes. The Australian cohort was unique. Data for the unit was incomplete until 2007. Nevertheless, it showed the University hosted the largest number of Low-SES students in the country. 60% were first in a family attending university. They came from any one of 150 nationalities and ethnic groups (Universities Australia, 2016). Equity issues were only measured since 2012 and other data was not detailed on per unit basis. Information gathering relied on students' willingness to offer it (e.g. Low-SES, private or public school, first/second/third generation migrant, Ma Engineering students in the unit). The industrial design program intake mirrored the national productivity decrease in manufacturing with a downward attrition trend for a decade (22 students per year inferred). This trend that averaged to 50% retention started to revert in 2013 (Table 8).

Table 8: Students enrolment 2007-2014

Year	2007	2008	2009	2010	2011	2012	2013	2014
ID Course Enrolment	**230**	**197**	**176**	**168**	**158**	**144**	**132**	**142**
D&T Course Enrolment	83	87	72	104	91	74	83	82
ID/D&T Course Enrolment	**313**	**284**	**248**	**272**	**249**	**218**	**215**	**224**
Attrition based on previous year	-15	-29	-36	+24	-23	-31	-3	+9
Unit Enrolment	**47**	**50**	**22**	**39**	**39**	**41**	**49**	**22**

Note: Reprinted from data provided by Western Sydney University's Office of Quality and Performance, 2016

SFUs' qualitative psychometric surveys comprised 13 items Likert scales and voluntary comments ('best', 'need improvement') that showed the following results for the 2007-2009 and 2012-2014 periods (Table 9)

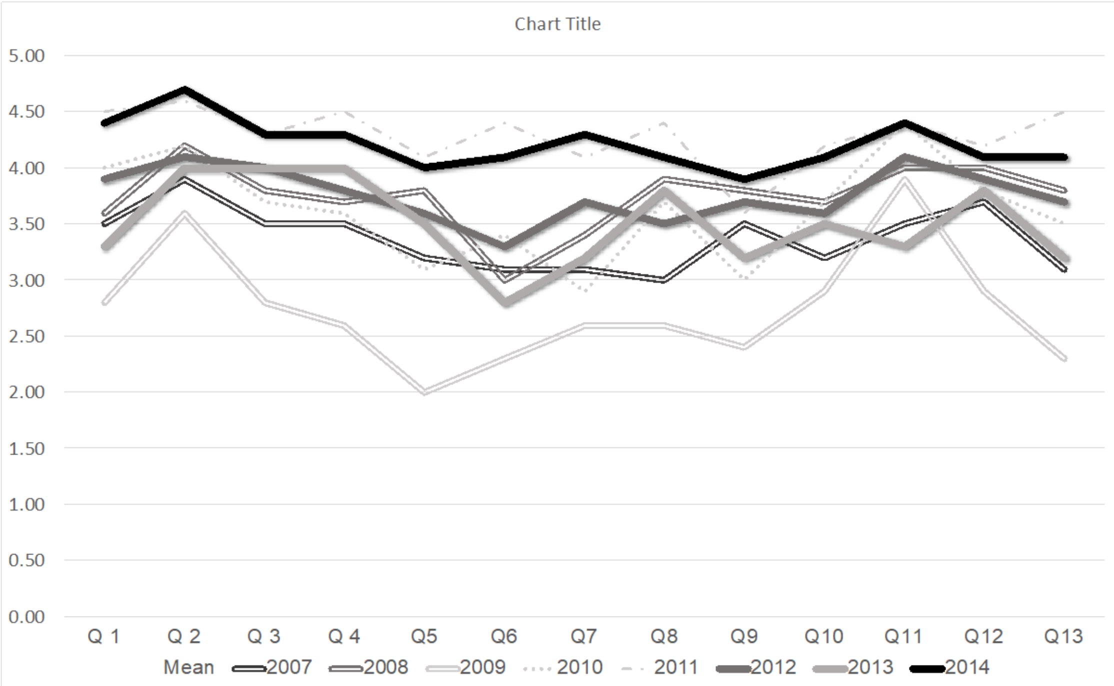
1. Positive 2007-2009 and 2012-2014 relevance on equity, fairness, critical thinking, analysing, problem solving and communicating skills
2. Negative 2007-2009 feedback on assessment methods and guidelines. Unpacking data and overall experience year per year revealed that:

   a. 2007-unit feedback was below the School mean as students were the first group experiencing this disruptive transformational model.
   b. 2008-unit feedback overall experience was parallel with the School mean
   c. 2009-unit overall experience was below the School and University mean, as students pointed to sudden loss of design studio workshop, machinery, resources and technical support
3. Positive 2012-2014 feedback on assessment methods and guidelines was either equal or better than traditional teaching results in the form of:
   a. 2012-unit overall experience above 2008 results.
   b. 2013-unit downturn was likely to suffer from sampling bias result of a total 13% response. The University statistician commented that participants who are in disagreement fill surveys more than those who are fine with a unit.
   c. 2014-unit overall experience was mostly above the School/University mean.

Psychometric attitude surveys revealed further limitations relating their inherent kind of measurement and potential numerical errors. Several studies (Backer, 2012; Centra, 2003; Denson, Loveday, & Dalton, 2010; Greenwald & Gillmore, 1997; Kulik, 2001; Marsh, 2007; Ory & Ryan, 2001; Pegden & Tucker, 2012; Theall & Franklin, 2001) showed that those tests work better with direct individual skill-task acquisition are partial against transformational learning since the latter becomes evident over time beyond a singular unit. Psychometric attitude surveys measure isolated units with the assumption that students know what the benchmarks in education and industry are. Therefore, it is difficult to distinguish whether feedback is objective about a unit or reflects parallel issues or legacy from previous units. Also, universities use them to assess academic performance and promotion. Subsequently, academics may fall into strategies to avoid adverse response, influence perceived benefits or grades leniency.

For example, this eight-year research revealed students' background and insularity from design and innovation mainstreams were not visibly enhanced by the time they reached the unit. 2009 SFUs were the only platform for students to express their views at the front-end when losing workshops, labs, equipment, and technical support for this capstone unit and the course. Numerous students did not know that loss belonged to larger changes to infrastructure that proposed the industrial design course should be taught through digital simulation in students' laptops. Likewise, the University statistician identified the 87% of students who did not fill the surveys was as meaningful as the 13% that responded them in year 2013. This research foresaw a group, such as the latter, would be dissatisfied since EL requires students' self-reliance and ownership. Stages 2 and 4 comparison showed SFUs improved visibly from 2012 alongside fixing the course's direction and infrastructure problems that allowed for critical making and pivoting to blossom. Students concentrated on bridging gaps they had between previous teaching, industry and user benchmarks pursued in the unit. The last three-year period showed similar or better results than the School and University mean averages and targets; many of those still based on transmission teaching models.

Table 9. 2007-2009, 2012-2014 Qualitative psychometric attitude results



Year	2007	2008	2009	2010	2011	2012	2013	2014
Unit Enrolment	47	50	22	39	39	41	49	22
Quantitative Survey Feedback (Results in Graph above)								
SFUs Returned	26	40	14	23	28	26	6	7
Response rate (%)	41	74	56	56	67	62	13	27
Qualitative Survey Feedback								
Best Aspects (No. of comments)	20	19	2	N/A	N/A	17	6	6
Unit Learning (%)	90	95	100	N/A	N/A	82	100	100
Unit Management (%)	5	5	0	N/A	N/A	6	0	0
Technical Support/Space (%)	5	0	0	N/A	N/A	12	0	0
Needs to Improve (No. of comments)	19	19	12	N/A	N/A	15	7	6
Unit Learning (%)	10	10	0	N/A	N/A	0	0	0
Unit Management (%)	42	42	40	N/A	N/A	94	100	100
Technical Support/Space (%)	48	48	60	N/A	N/A	6	0	0

Likert Qualitative Psychometric Attitude Survey (13 Items)			
1.	Unit Content: Unit covered what outline said it would	2.	Relevance: I was able to see relevance of this unit to my course
3.	Learning Design: The learning activities in this unit have helped my learning	4.	Assessment Activities: Assessment in this unit have helped me learn
5.	Assessment Feedback: I was able to learn from feedback I received in this unit	6.	Assessment Guidelines: There were clear guidelines for all assessment tasks in this unit
7.	Learning Resources: The learning resources provided helped me to engage in learning	8.	Learning Flexibility: The unit provided a reasonable amount of flexibility for study
9.	Learning Spaces: Teaching and learning spaces used for this unit were adequate	10.	Workload: The amount of work required in this unit was reasonable
11.	Equity/Fairness: In this unit, people treated each other fairly and with respect	12.	Generic Skills: This unit helped me develop my skills in critical thinking, analyzing, problem solving and communication
13.	Overall Experience: Overall, I have had a satisfactory learning experience in this unit		

Note: Reprinted from data provided by Western Sydney University's Office of Quality and Performance, 2016

Discussion

This research proposed active participation of students, industry experts, government officials and final users to figure out interactions not usually considered between people, technology and their environment. It focused on two areas currently challenging for industrial design. The industrial age productivity models are no longer enough when the profession is now globalised and dematerialising, while educational institutions also experience an increasing gap between their offerings and leading innovation benchmarks. Digital, physical, visual, and written data gathered showed that design education can add meaningful value to students and industry, so they create new means of production and social progress through leading knowledge and design-driven innovation. However, there were also a number of issues brought into attention.

As per Urry (2005), the project reappraised modern learning challenges in an environment that simulated complex global contemporary contexts and promoted social knowledge construction, experimentation and participation. Its strength was that it ran opposite to typical expertise that focused on basic discipline's technical skill acquisition. Many students did not fit the traditional profile of those who excel in tertiary education and working life. They were prepared mainly to execute closed briefs given by academics who assumed end of value chain manufacturing scenarios. Consequentially, students lacked contextualisation, critical making, HCD and pivoting thinking competencies when they reached the unit. Benchmarking considered user needs and students' background and experience to open opportunities for a unique learning culture. Thereby, the project value-added to education and industry with its participatory and design-driven mediation. This showed that students were able to shift into transformational learning in one semester. They were better equipped for employment when connecting upbringing, talent, and skills with contextualised environments, needs and resources. Also, they increasingly realised they could apply their skills and competencies to wider and newer areas for design intervention at a time the discipline is being redefined as post-industrial design in this 21st century.

Auxiliary questions for this research were also shown as interconnected. Typical industrial design education was based on transmission models that were indifferent to students' background and experience. Design intelligence development was limited because of students' lack of identification with projects, tasks, their meaning and purpose. The capstone unit promoted transformative improvement when customising knowledge construction and learning through heuristics of play and experimentation. However, one unit at the end of a course was not enough to revert three years of skill reproduction and transmission. Real change would come from establishing a new culture of learning from intake into the course. This was a point that Australian participants noted; their curriculum was highly regulated, high-tech focused, expensive and delegated tasks to technical support (e.g. machinery use, 3D printing and modelling). Initially, they shied away from industry involvement, coaching and collaborative work with others locally and abroad. By contrast internationally, Chilean participants ideated, developed mental and conceptual models, and took design artefacts through failure testing and up to working model stage manually from discarded or recycled materials. 25 participants each season came from a waiting list of 278 (300 students in their course). Their IDS project was an extra unit outside curriculum required for graduation. Most students were not bilingual. Yet, they prepared lengthy for dissertations in English via live video conferencing. Similarly, the Canadian and German students were used to work in collaborative communities of learning and used flexible and mediated technologies.

Such examples show curriculum may set autopoiesis, ZPD and 3GCHAT mechanics. However, knowledge externalisation, internalisation and cognitive progression do not happen if individuals are passive and incapable of socialising, owning and modifying the structures that precondition them. Australian participants repeatedly said the capstone unit helped them changing from a ‘ticking the box’ mentality to realising the importance of querying activities and making them worthwhile to resolve user need through empathy, customization and social construction of knowledge. Design research was a mediating activity that allowed potential innovation when blurring and crossing boundaries (Rancière, 2006) among students, users, industry coaches, experts, media, physical and digital materialities. Solving wicked problems through making and WIL helped students to figure out user and technology obstacles represented by information access and overload, physical-digital divide, training and socialisation breakdowns (Jenkins, 2012; Jenkins, Purushotma, Weigel, Clinton, & Robison, 2009). Customisation was critical for mediating tools such as mental and conceptual modelling, PAR, DWR and CDIO within an emerging sense of openness, unpredictability of outcomes and multiple futures that shape physical, digital and non-linear relationships across time and space. Visualising that diversity assisted students to map from a minimum discipline progress they might achieve to the promise of a new frontier of transdisciplinary implementation for industrial design.

Each year, students made post-mortem recommendations freely. These were compiled as tipping points that may trigger transformational learning as long as academics, institutions and students show the same willingness that participants in this project had. The rewards would be invigorated design learning and innovation when traditional professional practice suffers of diminishing industrial age manufacturing application. Students’ concerns were how to change education to benefit the next generations. Repeatedly, they suggested the transformational model would work best if implemented through the complete course. A new course was formulated by 2014 for a launch in 2016, after more than a decade that our university asked for course reformulation. The course introduces students to the current 4.0 industrial revolution of smart manufacturing, automation, data exchange, cyber-physical systems, decentralised decisions and internet of things that enables artificial intelligence, creates virtual copies of the physical world and also generates intelligent devices threatening to take over means of employment from traditional industrial designers (Bledowski, 2015; Kagermann, Helbig, Hellinger, & Wahlster, 2013; Shafiq, Sanin, Szczerbicki, & Toro, 2015).

The following 10 tipping points were compiled based on students critical making experience in the unit. Several suggestions coincided with recommendations coming from experts in modern theory of design that consider from individual background and experience to institutional policy and practice within a growing hyper-complexity of organisations, products, technologies and socialities:

1. Approach: To shift units from allopoietic and convergent teacher-centred transmission to student-centred transformation characterised by autopoiesis, critical making, pivoting and expansive learning
2. Boundary Crossing: To connect academics and students as participants within units and across courses to break away from skill silos
3. Curriculum: To apply the capstone model to the whole course. Students wished they had worked like that from first year since they only learnt design research methods and heuristics at the end of the course
4. HCD: To replace aggregated skill acquisition with solving wicked problems as design challenges emerge together instead of following one another (Lawson, 1980; Rittel & Webber, 1973)
5. Methodology: To implement meaningful agile development that is contextual, CDIO, empathetic, design research and participatory driven
6. Modelling (Mental): To model system's causality and simulate competing small-scale prototypes of reality to facilitate reasoning, foresee actions and trigger explanations (Craik, 1967)
7. Modelling (Conceptual): To design abstract, digital and physical system prototypes to make problems and solutions graspable to participants (student, users, other stakeholders), and assist modularity and scalability (Norman, 2013).
8. Participation: To implement PAR, DWR and WIL with dynamics of discussion, inquiry, iterative making and reflection among participants (students, users, other stakeholders),
9. Transformative Learning: To implement EL based on cognitive, social constructivism and constructionism that customises learning based on individual and group background and experience, and how students can connect with the larger reality of industry, society and technology.
10. Triggers: To implement series of empathy activities to trigger cultural, suspend pre-conceptions and uncover people's unspoken needs within activity systems (Leonard & Rayport, 1997; Leonard & Sensiper, 1998).

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Innovating Industrial Design Curriculum in a Knowledge-Based, Participatory and Digital Era

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Abstract

This article discusses three years' research (2012-2014) on design education towards a 2016 undergraduate industrial design curriculum launch. It contributes a pathway for conservative courses towards design culture transformation and filling gaps between them and leading breakthrough education exemplars. The course proposes a collective knowledge creation model through social constructivism and constructionism that recognises its place in time and history and allows customisation to individual upbringing. It catches up with a profession transformed beyond a digital Bauhaus manifesto that joined and revaluated physical and digital artefacts as per their environment, quality of experiences, intelligence, networks and relations. Data and findings supported pedagogy redefinition from master-apprentice and teacher-centred skill transmission models to heutagogy and paragogy. The new approach required habitus change from a traditional goods-centred discipline to human-centred focus, critical design and making, design heuristics, CDIO (conceiving, designing, implementing, operating) and STEAM (science, technology, arts, mathematics) frameworks. Participants empathetically contextualised, problem framed and solved by crossing boundaries between disciplines, institutions, industries, students' background and society. Research and practice promoted new forms of industrial design creation happening in physical and digital coexisting spaces of being. Course units evolved around an e-curriculum component working as a digital spine. Curriculum progressed from standard top-down transmission to sociotechnical and organisational networking, industry collaboration, international design studio and Design Factory model-like projects. In doing so, it became a foundation for future physical-digital industrial design artefacts, human computer interaction, machine learning, hacker culture systems, shared information, free open-source software and hardware development within a 4.0 industrial revolution.

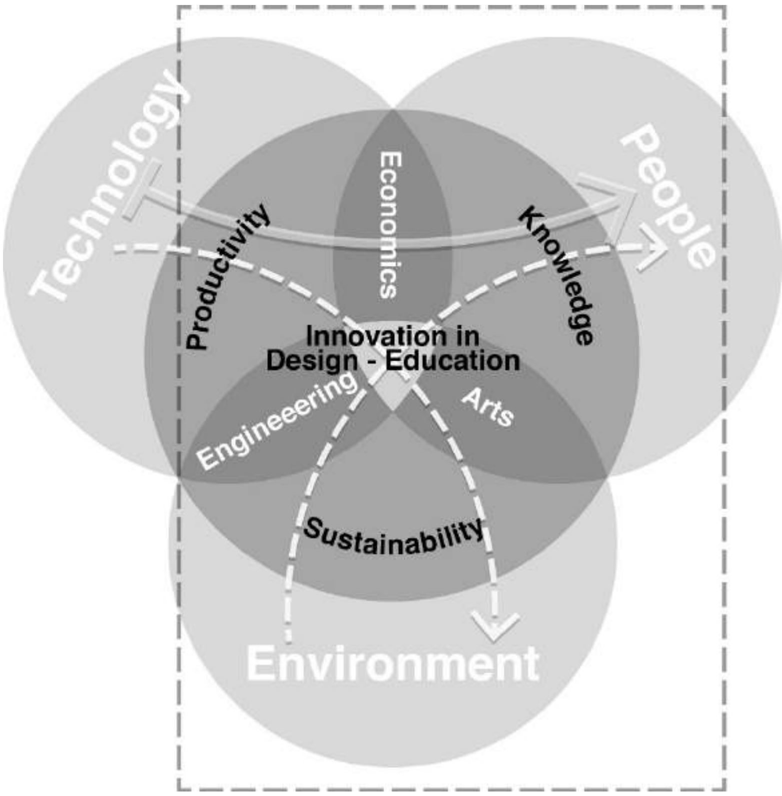
Key words

cultural-historical activity theory, constructivism, constructionism, CDIO, design education, STEAM

Introduction

Experts propose design has cultural significance beyond wealth creation and situate designers as change agents, culture generators, and reference point for policy makers and intellectuals of the future (Hustwit, Beshenkovsky, Geissbuhler, & Dunne, 2009). These claims evoke Bauhaus artist-designers' aspiration to lead society into social wellbeing from a century ago. Yet, today many designers lack the intellectual and commercial preparation to lead business, politics and social change. Numerous industrial design educations are still linked to specialised assembly and manufacturing, while higher education relies on massification of teaching and strong preconditioning of outcomes for its survival. We live in a knowledge-based economy, decades after a digital Bauhaus manifesto that transferred design meaning from mass production to experience and knowledge creation. Timely, this article discusses an undergraduate design degree makeover (2012-2014) which focuses on an individual and collective knowledge production model through social constructivism and constructionism. It redefines design artefacts as tangible and intangible knowledge-based capital that realigns cultural, historical and spatial setting to address relationships between environment, people and technology. Design heuristics help overcome the physical-digital divide with empathy, contextualised human-centred and experiential design, and crossing boundaries between disciplines and participants. Social constructivism defines cognitive processes as knowledge construction by learners through their own distinctive system of knowing, making and modelling. Constructionism means the physical, digital and social process by which those creations materialise through continuous conversation, interaction, critical design and making.

Educational institutions play a pivotal role in the past and future of social development, whereas curriculum imparts discipline rules and prepare students for the profession. Course culture is thus determined within the push-pull between environment, people and technology that challenges established conventions (Figure 1). In particular, design courses' agency depends on innovation while still suffering unresolved dilemmas. A definitional crisis polarises programs between the extremes of artist-designer (inspired creative genius) and engineer-designer (scientific calculation resolving complicated problems). There is also a gap between well-funded benchmarks and design education that frequently struggles economically because of normative constraints and increasing



pressure towards massification of higher education. New, cheaper information and communication technologies (ICT) further redefine human relations, their space and time dimensions (e.g. face-to-face, mediated, distributed, augmented) while also replacing traditional professions. Lastly, academia is experiencing rising demands to develop competencies not available in standard design education (e.g. collective, creative, empathic). Fittingly, this research aims to answer: *how can an industrial design curriculum enable participants' knowledge construction to develop a design-driven innovation culture in a digital era?* Supporting this, there are questions of how to:

A. Update curriculum when design artefacts are no longer physical only?
B. Diminish uncertainty and stimulate constructive collaboration?
C. Bridge the physical-digital divide while transforming participants from technology consumers to active cultural producers and mediators for social benefit?

Figure 1: Environment, people and technology push-pull challenging design education. Reprinted from Author, 18 January 2012, Vision for Industrial Design Course: Presentation to Directors of Academics Program Panel, Unpublished internal document .

Method

This paper firstly uses epistemology to define and contextualise the challenge of industrial design in the current knowledge-based, participatory and digital era. Particularly, research on theories of knowledge that look into what constitute a design artefact, its historical context and effects on pedagogy. Cultural-historical activity theory was found to suit the process of course reformulation best. The paper then looks at the second step in this project that focused on a curriculum development that recognised education and technology benchmarks, and developed a new course with collaborative and interventionist research approach to re-address design education for current times:

Results

Epistemology

The Design Artefact

Design artefacts have experienced semantic shifts alongside social and technological changes. Industrial design has primarily persuaded society through physical artefacts. These were understood as *objects* (entities with purpose), as opposed to *things* (natural entities independent from human intention or no longer serving function). Artefacts resulted from applying practical skill (Latin *arte*) to make well and good (*facere*) 'man-made' statements (*factum*). Social and material culture experts assumed them as tangible, ready-made and matters-of-fact (empirically measured) material properties capable of influencing human behaviour. Yet, a design artefact is not just an artefact. It is also a technical object. (Greek *techne:* crafted, manufactured, systematic). Concepts of truth, belief and socio-environmental connections affected how they carried knowledge.

Originally, the English word for design came from old Greek past tense (*eschein*) for *to have* or *possess something.* The embedded meaning was about loss of possession which required artefact representation to prevent humans from forgetting (Terzidis, 2007). Its Latin root (*de*: out, *signare*: drawing a sign) meant marking to preserve mental images. Latour (2004); (2008) argues that design became exhausted last century as it turned into superficial stylistic representations (*relooking*) as veneers of fashion taste. He proposes a constructivist approach *redrawing* two disconnected narratives together. One of emancipation, detachment, modernisation, progress and mastery, and the other completely different of attachment, precaution entanglement, dependence and care in favour of *redesigning* effective nature and society ecosystems (e.g. climate change, equity, globalisation). Current problems are too multifaceted to condense as material matters-of-fact and input-output productivity. Design artefacts must transform from image representation to purposely constructed things capable of addressing matters-of-concern (undefined with relative implications) by appropriate processes that solve ambiguous and complex challenges.

This curative design strength can help us re-evaluate artefacts beyond *possession* (consumption) and *relooking* (fashion) to *re-seeing* and *seeing-through* solutions for humanity and nature as acts of iterative meaning construction. Consequentially, design is better defined with active verb expressions (e.g. making, modelling, testing) with non-finite properties in process of continuous development and interpretation. As with Dutch description (*ontwerp*), projected modelling inquires the present to improve future realities through research, collaborative and evolutionary improvements. Design education can futureproof discipline and students by teaching design artefacts which are epistemic instruments. They are characteristically fluid, non-static permeable and porous to their context, environment and users. A four knowledge construction periods timeline (Figure 2) assists understanding design artefacts' past and future incarnations as:

1. **Product-Production:** Craftsmanship representing inspiration on constructed (a priori) knowledge.
2. **Process-Method:** Industrial and material applied research for forming and mass production.
3. **People-Participation:** Intricate challenges represented by people as consumers (e.g. behaviour, cognition), and the start of the electronic era (e.g. information, productivity, technology).
4. Stages 1-3 are characterised by linear, simple and complicated problem-solving needing passive or restricted user operation to complete them (e.g. cars, chairs).
5. **Place-Time-Practice:** Design artefacts as projects figuring out complexity and users (e.g. choices, decision-making, experience) through practice and forward (posteriori) knowledge construction in undefined environments. This requires active *redesigning* of artefacts as presentative platforms needing user intervention to generate and regenerate design (e.g. apps, coding, artificial entities). Characteristically, it involves co-creative and empirical habits based on empathy, discovery, participatory action research (PAR), modelling, and customised forecasting and production. Since people can now design their own artefacts while identity and knowledge are easily reconfigurable through physical-digital

materiality, spaces, time narratives, networks, cyber-culture, 4.0 industrial revolution's automation, generative design and artificial intelligence.

Historical Context

Most industrial designers are Bauhauslers because of heritage. Bauhaus (1919-1933) merged art and technology to democratise industrialisation. Gropius' manifesto denounced artists and designers as glorified craftsmen-decorators, and aesthetes who were isolated from their socio-historical environment (Gropius, 1919). He opposed *pedagogy's* (Greek *paida*: children, *gogo*: to lead) master-apprentice model that guided passive students via transmission and task replication (Herbart, 1806; Majorek, 1998). Bauhaus was influenced by other movements (e.g. Deutscher Werkbund, Novembergrouppe), intellectuals (e.g. Weber, Frankfurt School of Social Sciences) and Dewey's re-imagining of learning as problem-based, hands-on, pragmatic education (Bergdoll & Dickerman, 2009; Dewey, 1902; Maciuika, 2005).

A 6-year constructivist artist-designer syllabus consolidated industrial design past crafts and draughtsmanship into higher art by making it inseparable from research and social implication (Armengaud, 1853; Betts, 2004). Learners' iterative trial-and-error experimentation heuristics (Greek *heureskein*), transformative dialogue, prototyping and testing started from foundational analysis to nature, science (e.g. manufacturing, mathematics, geometry), comparative studies, and final specialisation. Unembellished design artefacts were the archetypal integration of research science and visual arts, artist and machine aesthetics (Dondis, 1973; Saletnik & Schuldenfrei, 2013). Ground-breaking, Bauhaus-visible influence gave designers moral value with worth beyond productivity. Social change resulted from artefacts' immediacy as "it is impossible to procure knowledge without the use of objects which impress the mind" (Dewey, 1975). However, Bauhaus did not translate well elsewhere.

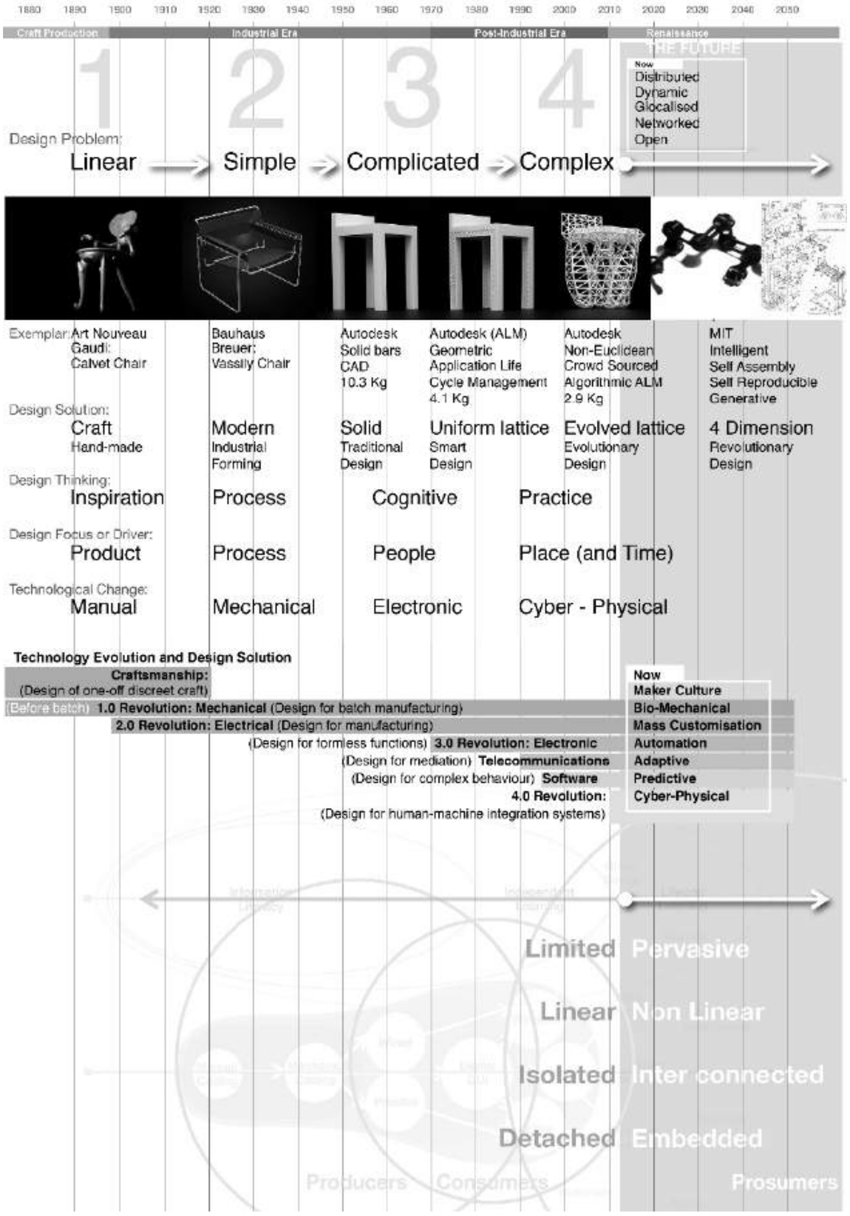


Figure 2: Industrial design's four knowledge construction eras. Reprinted from Author, 27 October 2014, Industrial Design Curriculum 2016: New Vision and Imperatives for the New Normal of Innovation and its Education, Unpublished internal document.

Mostly in post-war United States (U.S.) and United Kingdom (U.K.), many designers, educators and intellectuals tried to engineer society. As an example, the International Style kept Bauhaus functionalism minus its social significance. Asemantic modernism rejected ordinary human, social and geographical interests. Government, corporate and education projects used design as instrument of control that befell users unable to connect with it. Experts predicated rationalistic methods would automatically make the world better by stringent procedures. Thus, design followed collected computing data, logical deduction and mathematical optimisation models (Miller & Tilley, 1984). Simon advocated artificial intelligence would do any work a man did within 20 years (Simon, 1969), while Habermas critiqued the notion of social engineering replaced the old with a new Enlightenment promising to solve all problems (Habermas, 2012). People became dissocialised consumers at the mercy of financial markets. Designers and their artefacts became mythical high-tech commodities under technologists' control that permeated society and institutions (e.g. academia, law, sciences) with self-supporting processes empty of meaning (Lyotard, 1984; Zuidervaart, 1993). Adorno pointed to increasing fetishism the further meaning was lost in the push-pull among production and malfunctioning people's social mechanisms (e.g. arts, communications, culture experts, education) needed to figure out their alienation (Horkheimer, Adorno, & Noeri, 2002).

Elsewhere, in Germany and Northern Europe, design went beyond artist-designer and engineer-designer ideologies to set the foundation for human-centred design (HCD) and education thereafter. The HfG Ulm School (1953-1968) proposed design as an everyday life discipline assisting national reconstruction. Idiosyncratic research methods converted consumers into user-participants who integrated technology and culture through design (Olt Aicher, 1919; 1994; Krippendorff, 2008; Maldonado, 1958). Ulm's research-driven and project-based program built on humanism, pragmatism, semiotics and Frankfurt School principles. The 4-year course had a collaborative first-year introducing students to 4 interdisciplinary pillars: industrial design, building, visual communication and information. Gorman (2003) explained that practice and theory focused on cultural theory, chemistry, mathematics, methodology (e.g. logic, permutations, topology), perception, physics, presentation (e.g. drawing, drafting, language, typography), sociology, visual methods (2 and 3-dimensional experimentation), and workshop (e.g. metal, photography, wood). Ulm argued that information technologies transformed artefacts' material qualities and users into abstract data with a new concept of industrial duplication. Representation became more important as technocrats' decision-making and modelling perfection succeeded only if human subjective interference was eliminated (Maldonado, 1972). Yet, design was neither science nor engineering or artistic intuition. Instead, it was defined by artefacts and users' activity, interaction and values. This freed design artefacts from material-oriented views conceiving that industrial design was to solid materials as graphic design was to paper (Bonsiepe, 2010; Oswald, 2012).

After the 1970s, following phenomenological analysis of style, methodology and industrial production, design thinkers proposed design as a third creative culture in-between the two traditional ones of humanities-social sciences and science-technology (Archer, Baynes, & Roberts, 1992, 2005). Cross (1982, 2001, 2007) categorised design research as either by, for or through design. Others argued designers are sense-making beings rather than problem solvers only (Dorst, 1997; Dorst & Dijkhuis, 1995; Gedenryd, 1998). However, Ehn (1998) was the one who indicated academia had fallen behind from Bauhaus and HfG Ulm bequest. His Digital Bauhaus Manifesto offered a multidisciplinary, reflective and participatory course at Sweden's Malmö University. Students merged arts, crafts, design and technology. Design expanded to interaction, participatory design (PD) and human computer interaction (HCI) in an experience economy. Design embraced a digital revolution that transgressed material space, time, culture divisions and hard (e.g. materials, manufacturing) and soft (e.g. coding, ethics, management) technologies. Artefacts, environments, participants and time no longer followed linear patterns. They also became virtual and fluid. Consumers as users were present, mediated, distributed, co-present or augmented through participative creation of interactive narratives.

Two decades on, education is slowly adapting to experience design while users are knowledge workers already living a knowledge-based and innovation-driven economy.

They work on non-routine problem solving and independently produce new knowledge and ways to transmit it as portable capital assets regardless of their position in a globalised market (Drucker, 1999, 2011). Fittingly, Bremner and Rodgers (2013) said design is in a 40-year crisis as a "discipline without a discipline". Concerns are that professional strengths are hijacked by non-designers (Cruickshank, 2014; Lockwood, 2010; Martin, 2007; D. H. Pink, 2006). Business, local authorities and marketing use design methods as common sense, non-ideological and depoliticised technics (e.g. IDEO's Design Thinking). Thus, non-designers may sacrifice design's innovation if applying its methods as replicable templates that are indifferent to problems of complexity, contexts and users (Jacob, 2013). Design can again solve the disconnect in society by *re-seeing* the industrial (Latin *industria*: diligence, manufacturing) in design with a new meaning for manufacturing (Latin *manu:* human intervention, *facture:* making) and wellbeing. Success cannot be measured by production efficiency and fashion as before. Instead, it should be by defining outcomes at the other end. Precisely at the moment of design artefact *instantiation* when users negotiate design artefact effectiveness. This notion expands designers' mediation to any field with similar application of its principles, theory, or classes of objects. It helps to establish new dialectics between humans and artefacts, and among artefacts. This is a welcome diversification as industrial design based on material production is changing. Today's high-tech design, computer power and hard technology may cost as little as US$5.00 by 2032 (Stross, 2014).

Pedagogy

Design education agency depends on pedagogy that can reflect the productivity shift from conspicuous consumption to globalised design-driven digitalisation, experience and knowledge. With good timing, Fallan (2010) credited industrial design with building a discourse increasingly independent from art and based on context and artefact-user interaction. However, the education business is hazardous. Institutions often suffer contradictions that still affect pedagogy with the legacies of the last century. Funding constraints increase pressure to massify education to loss of critical thinking (Liem & Sigurjonsson, 2014). Pope (2016) states that curriculum is used as political tool that organises, codes, mediates and administers power. Others denounce a slippery slope with a neoliberal agenda that uses technocratic measures as a Trojan horse, where managerialism forces teachers into predefined learning outcomes and instrumentalised education away from quality and critical reflection (Gleeson, 2013). Logically, universities constantly invest in infrastructure to improve their visible clout and maintain claims of excellence. Also, ICTs are often sought after to maximise performance, as they are cheaper than face-to-face and project-based learning. Yet, large and costly physical projects run in opposite directions to digital knowledge flow costs that are becoming portable, transmittable and free for users within and outside those institutions. Technological disruption also brings new players intending to control communication, education and news on strength of social networking and algorithmic formulae (e.g. Facebook, Google).

Admittedly, Gropius' departure from the Beaux-Arts academy had a first-year intake more prepared and a course longer than ours. Yet, Bauhaus underscored the significance of active construction of knowledge through heuristics. It ran against trends that maintained the asemantic and preconditioned status quo through modernism and post-modernism.

19th century *pedagogy* and 20th century adult education (*andragogy*), behaviourism and Bloom's taxonomy, all pursued the approach of efficient skill transfer as instruction that pre-empted behaviour before it had occurred (Alberto & Troutman, 2012; Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956; Herbart, 1806; Kapp, 1833; Knowles, 1980; Skinner, 1974; Watson, 1913). Prescriptive environments greatly disregarded participants' critical (Greek *kritikos*: discernment) state of mind. In this century, technology may add to that tendency against learning if Web 1.0 (data broadcasting), 2.0 (personalised information), 3.0 (peer-centred, semantic web) and 4.0 (open, linked, intelligent cyber-physical generation) evolution is thought as solved with ICT decontextualised from changes to ideology, users and environment.

Recent pedagogical models explain learning for our times as decentralised, experiential, transmediatic, peer-centred and crossing institutional and disciplinary boundaries indifferent to physical and digital dimensions (Table 1). Self-determined discovery (*heutagogy*) and peer-to-peer generative learning (*paragogy*) can extend Bauhaus' and Ulm's constructivist and critical theory framework. They encourage learners to query users and environment, improve and influence the social, historical, and ideological structures that produce and constrain them (Corneli & Danoff, 2011; Corneli, Danoff, Pierce, Ricaurte, & Macdonald, 2015; Hase & Kenyon, 2013; Kenyon & Hase, 2001). Fittingly, (2012) epistemology schema helped curriculum development as a query for changing the status quo through physical and digital artefacts and activities (Figure 3). Based on a metaphor of centres, he showed that technical simplification, top-down and fundamental universal control on design do not help in making sense of and solving current complex, distributed, dynamic, networked and open challenges, because:

- *Abandoned-centre* frameworks show typical industrial age syllabus that imparts skills as single discipline 'true particular'. Academics risk siloism within walls of technology, specialisation, lack of shared understanding, content and purpose.
- *Soft-centre* models represent belief on 'universal' generalisable truths that cross over discipline boundaries as with cross-, inter- and multi-disciplinary relations. However, stronger disciplines may take over younger ones. As with design, more powerful and evolved histories (e.g. arts, science, social sciences) have affected it because of a lack of an independent discourse.
- *Hard-centre* models propose individual discipline principles depend on a hard core containing fundamental universal laws (e.g. École des Beaux-Arts aesthetics, Bloom's taxonomy determinism).
- *Liquid-centre* structures show best suited as designers must be flexible and open to dialogue. Participants' beliefs and facts conform 'real particulars' that inform customisation, innovation, problem framing and solving, systemic perspective, and transdisciplinary collaboration.

Learning Attribute	Pedagogy (Herbart 1806)	Andragogy (Kapp 1833, Knowles 1980)	Heutagogy (Kenyon and Hase 2001, 2013)	Paragogy (Cornelli and Danoff 2012, 2015)
Etymology (Greek	*Peda*: chidren; *gogy*: I lead	*Andr*: man; *agogus*: leader of	*heureskein*: discover; *gogy*: I lead	*Para*: generation, *gogy*: I lead
Definition	Teacher directed children Instruction	Adult self-directed learning	Self-determined learning	Peer to peer learning
Motivation	Internal factors: Instruction	Internal factors: Instruction	External factors: Meta-learning	External factors: Meta-learning
Control	Institution	Institution	Learner	Peer-centered
Cause	Trade education	Further education	Wayfinding	Sharing, mixing
Model	Transmission	Transmission	Transformative	Transformative
Key query	What to learn	What to learn	How to learn	How to learn
Learning	Passive	Operational	Collaborative	Networked
Learner Role	Enters education not knowing	Enters education ready to learn	Learner-centered autodidacticism	Learner-centered skilled agent
Teacher Role	Teacher-centered (content, process)	Guide-mediator (content, process)	Moderator (process over content)	Influencer (content, process, practice)
Student Dependence	Dependent on teacher and strict curriculum	Independent as curriculum is optional	Interdependent among learner, teacher, users	Peers dependent (equals but different)
Focus	Skill transfer	Upskilling	Experimentation	Knowledge flow
Curriculum	Prescriptive	Discretionary	Critical thinking-making	Generative
Context	Centralized	Centralized	Decentralized	Decentralized
Classroom	Classroom based training	Supplementary to objectives	Studio, research workshop	Hyper-connected
Narrative	Discipline specific	Discipline specific	Transmediatic	Transmediatic
Resources	Teacher's classical student conditioning	Experience and pragmatic	Non-linear problem framing and solving	Crowd-sourcing and distributed
Outcome	Degree, employment	Performance, competition	Self-efficiency, effective innovation	Knowledge curation, redesign

Table 1: Pedagogy models in relation to design education and technology

Note. Based and adapted from Corneli and Danoff (2011); Corneli et al. (2015); Hase and Kenyon (2013); Herbart (1806); Kapp (1833); Kenyon and Hase (2001); Knowles (1980).

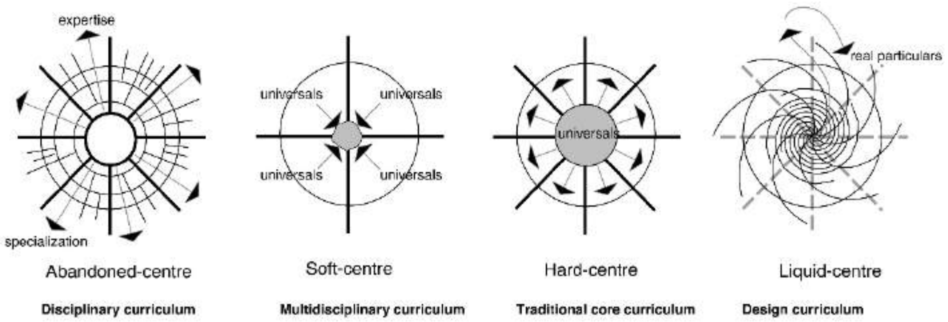


Figure 3: Design learning epistemology. Reprinted from Nelson, H. G. (2012). The Design Way: Intentional Change in an Unpredictable World (Second edition. ed.). Cambridge, Massachusetts: MIT Press, Copyright © 2012 Harold G. Nelson and Erik Stolterman.

1 Cultural and Historical Activity Theory

As per several authors, including Engeström (1987); (1990, 2001, 2009a, 2009b, 2014; 2010); Kaptelinin (2013); Khayyat (2016); Sannino (2011); Yamagata-Lynch (2010), cultural-historical activity theory (CHAT) intends to understand the relationship between humans' minds (e.g. thinking, emotion) and actions (what they do). In particular, this research focused on third-generation (3GCHAT) and fourth-generation (4GCHAT) theory. A first-generation activity theory (AT) attempted to provide a dialectical materialist analysis of mediating artefacts that revealed human mind and behaviour. These were cultural artefacts that broke with traditional explanation of reality as Cartesian dualisms (e.g. mind versus matter, individual versus rigid social structure). Society could not be explained away from individuals' agency in the production of knowledge and use of artefacts. Similarly, individuals were no longer isolated from their cultural means. Psychological and social stimulus and response depended on the mediation of those artefacts. This relationship was represented with a triangular model having mediating tools and signs (M) in the top vertex above a subject (S) and an object (O) that occupied left and right horizontal vertices below respectively. A second-generation theory (CHAT) made a case of reconstructing human activity's culture and history as indispensable to understand learning. That was achieved by expanding AT unit of analysis from individual action to a collective system defined by rules, community and division of labour. However, CHAT had methodological shortcomings presented by its focus on singular activities and a descriptive nature in relation to qualitative research in western countries.

Gaining momentum since late 1980s, 3GCHAT fitted the project as it proposed the researcher should take a participatory and interventionist role in participants' activity while avoiding being predictive and pre-emptive of their creative contribution. Collaborative process and analysis aimed to find and ask the right questions to figure out complex real-life problems rather than providing ready-made answers. 3GCHAT upgrade of AT recognised that mediating artefacts and objects "exhibit multiplicity. They represent multiple perspectives, voices, dialogues, contexts and boundary crossings" (Spinuzzi, 2015). CHAT also expanded from a single unit of analysis that focused on individual psychology to encompass the means capable of bringing about organisational change. This was a needed revaluation of the theory. Education and psychology mainly had not embraced the dialectical and materialistic conception of humanity as creator and transformer of culture.

3GCHAT multiple activity relations were investigated based on an activity system analysis (ASA) that built from a minimum expression of two-activity systems modelled as shown in Figure 4. Research depended on cultural-historical background, context, inner relations and contradictions between stages of production, consumption, exchange and distribution. Accordingly, specific circumstances affected humans' and non-humans participants' roles and degrees of influence within the nodes of that model from subject (observer), to object (person or thing observed or acted upon), mediating instrument (e.g. technology, tool), mediating activity, theory and practice (e.g. critical thinking process), power play (e.g. rules of management), community (e.g. socio-cultural capital), division of labour (e.g. people's allocated tasks), and outcomes as artefacts that were either physical, digital or abstract (e.g. products, services, theoretical models, behaviour).

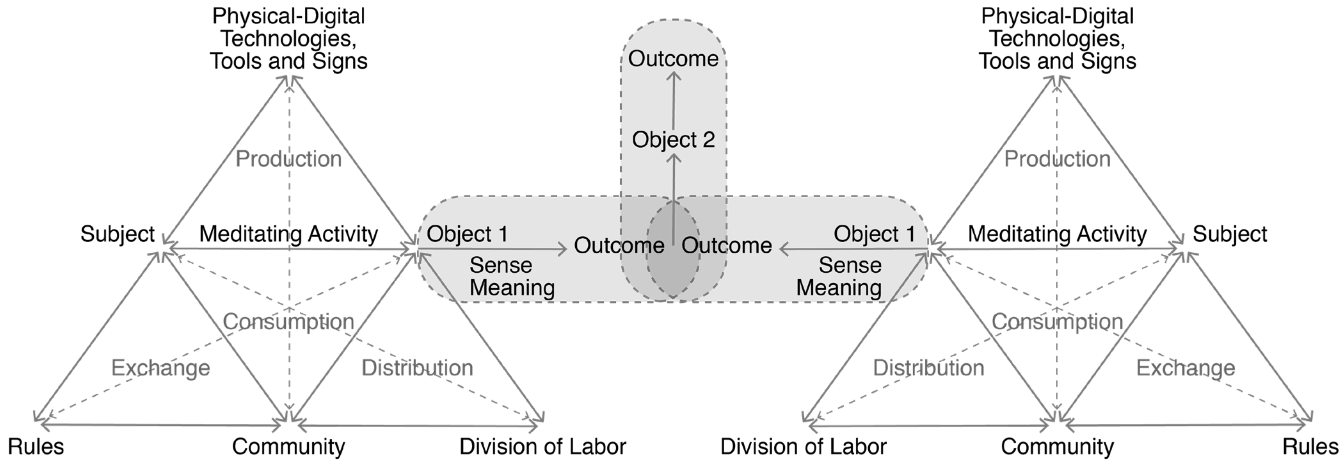


Figure 4: 3GCHAT model. Adapted from Engeström, Yrjö, 2014, Learning by Expanding: Cambridge University Press, Copyright © Yrjö Engeström 1987, 2015.

ASA captured change as it ensued instead of the way it was hypothesised. Researchers recognised CHAT's origin in psychology but revealed its concepts of activity and artefact had inter- and transdisciplinary nature and problems that could only be resolved by including other research fields. Design research in education and innovation was one such contributor since it focuses on the making and use of artefacts while crossing boundaries among disciplines, media and networks. Border crossing has already subverted traditional business talk about users and students as objects. Many professionals still design for an illusionary user that is assumed but not consulted. Similarly, universities tend to model education around an archetype of student (from Latin *studere*: applying oneself to, painstaking application) who individually acquires and is transmitted skills. Following (Krippendorff, 2005), there is a great need to include both users and students as active stakeholders in the process of design and education today. Recent trends have promoted the building of communities of practice (Wenger, 1998) and co-working in flexible and open workplaces. However, the former has proven ahistorical and reliant heavily on a sole craft or profession, and conditional on a single skill or authority emanating from a leader. The latter frequently results in a *working alone together* habit that is not conducing to border crossing and true collaboration (Spinuzzi, 2012).

Better yet, 4GCHAT upgrades communities of practice to a concept of *collaborative communities* particular to knowledge-intensive firms and learning that is cultural, contextual and historically based. It recognises that users and students bring with them contingencies not normally considered by old teaching models which prefer to simplify business and make it efficient. Engeström (2008); (2013) has named these contingencies *runaway objects*, referring to contested cultural and historical objects that have been traditionally disregarded and hidden. Runaway objects are not under any one discipline's control. They normally start as marginally small, with peculiar individual issues having a chance to grow if not considered. Their expanding influence generates opposition and controversy that can disrupt, and potentially emancipate, design and education by creating radical instances for development and wellbeing.

4GCHAT also upgrades co-working to *co-configuration* as a new scenario of dialogical knowledge production where designers, users and learners become guides, negotiators and boundary-spanners (individuals linking internal innovation systems). Co-configuration promotes sociotechnical networks that produce new knowledge, customer-intelligent artefacts, products and services that learn and adapt to individual experiences since humans endlessly create new objects, meanings and have changing needs. This is a new landscape of knowledge construction moving away from central authority, status or hierarchy to value-rationality that holds designers, users, lecturers and learners as peers of each other. Yet, co-configuration is frail. It depends on the time a project takes and the space it is held (e.g. closed, open, fixed, flexible, co-present, tele-present) before new teams form with another goal. Effective collaborative communities arise from co-creating values woven as *knots* in a grid of runaway objects, and contradictions that affect single discipline skills and participants (e.g. academics, students) in similar way to *mycorrhizae-like* activities (symbiotic association between fungus and roots that helps production of nutrients, growth, and underground communication among plants and trees).

3G and 4G CHAT were significant recognising that essential tinkering of design and learning (gaining knowledge by making) cannot be measured bi-dimensionally (length of schooling, technical skill width) anymore. Evaluation needed to be three-dimensional by including time and space as variables helping to discover participants' *knots* of relations, *runaway objects* and *mycorrhizae-like* activities that affect knowledge construction and learning (Figure 5). The time variable would assist contextualising a participatory curriculum evolution while the space variable would describe participants' depth of critical development. Active students as learners (old English *leornian:* to get knowledge, be cultivated) had to progressively tinker into deeper spaces of knowledge over time to form a *continuum* of artefacts (e.g. abstract, digital, physical, discipline and language related) and activities without preconditioned boundary. Hence, design learning had to its earlier cultural and historical base represented by phases of product-production, process-method and people-participation to recent complexity involving place-time-practice. Yet, those artefacts were not to represent general, global, and value-neutral knowledge as in the natural and social sciences. Counter to traditional disciplines, design developed artefacts for particular moments, purpose and people (Kuutti, 2005).

Curriculum Development

Curriculum and Infrastructure Benchmark

A new gameplay required a move from assumed knowledge and material-oriented descriptions to a curriculum based on informed knowledge. Course success depended on identifiable signatures that enable significance and attractive reputation. Students had to learn more (e.g. economy, environmental issues, politics, social sciences) and discover modern critical thinking, in order to shift away from technology's oppression to empowerment of people (Norman, 2010, 2015). Yet, widespread differences positioned design and education as contested concepts that needed contextualisation (Gallie, 1955; Tucci & Peters, 2015). The traditional definitions of industrial design by the Industrial Design Society of America (IDSA) and the International Council of Societies of Industrial Design (ICSID) as appearance and manufacturing of three-dimensional machine-made products, were especially telling. ICSID kept its 1957 definition until its 2017 relaunch as World Design Organisation (WDO). It then updated its definition of industrial design to the “strategic problem-solving process that drives innovation, builds business success, and leads to a better quality of life through innovative products, systems, services,

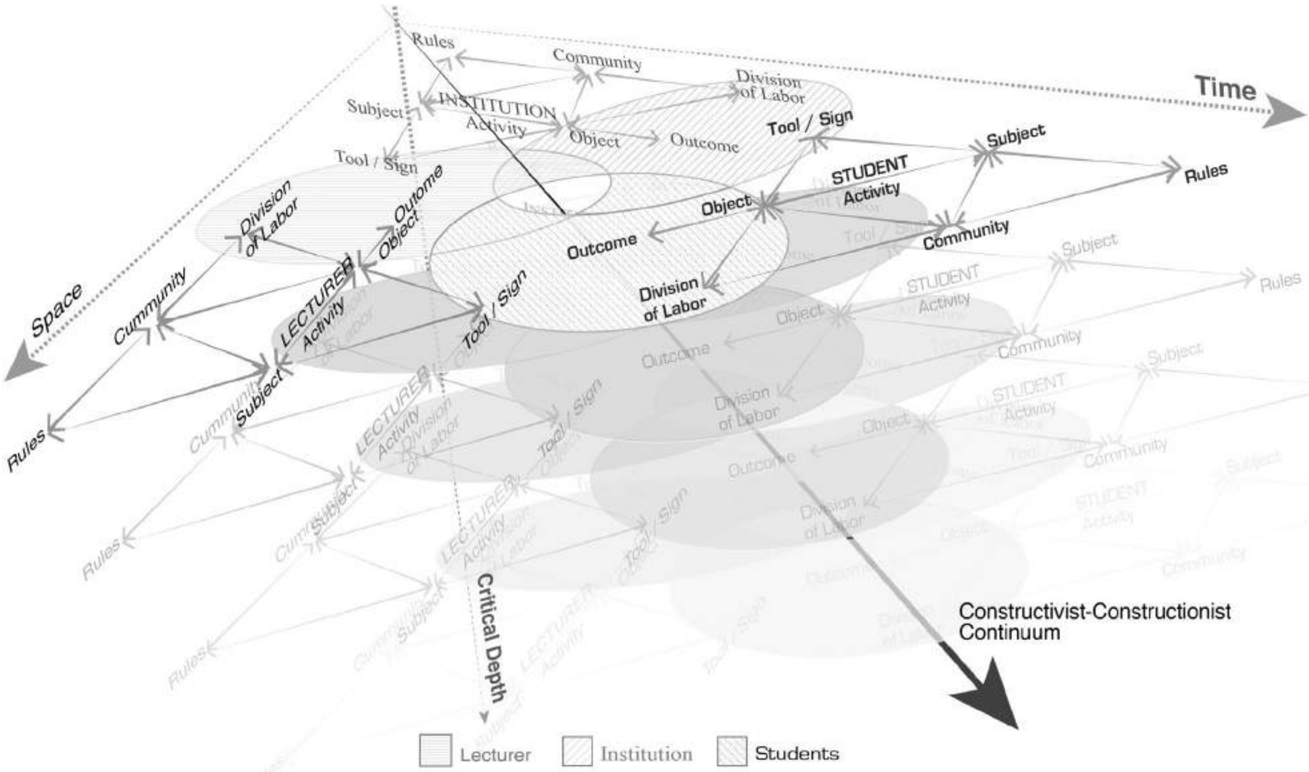


Figure 5: ASA course space-time paradigm. Reprinted from Author, 27 October 2014, Industrial Design Curriculum 2016: New Vision and Imperative, Unpublished internal document.

and experiences” (WDO, 2017a). This description intends to embrace extreme descriptions such as: “to entertain us, to make sure we are comfortable and warm, safe and wealthy” (Seno, 2010); “service design which does not stick to the product form but wisely used in all public fields” (Shenzhen Industrial Design Association); “primarily about better user experience” (Dublin Institute of Technology); or as the Strate School of Design, Paris, claim: “industrial design is dead, long live design! We define ourselves as a post-industrial design school’ …. ‘Today, the issues are no longer industrial ones. They are societal challenges; it is about’ …. ‘life quality’” (WDO, 2017b).

European benchmarks were seen as leading international breakthrough education exemplars to follow. Still, it was inappropriate to transplant ready-made solutions given that European redesignings were built on unique points in culture and history time ago. Instead, attention went to U.S. because of its influence on industrialisation in Australia and the U.K. Both had a similar Anglo-Celtic base to the Australian context and their *redesigning* happened more recently. Data showed a shift away from industrial assembly and manufacturing. The U.S. Bureau of Labor Statistics (2017a) described industrial design as “art, business, and engineering to make products that people use every day. Industrial designers focus on the user experience in creating style and function for a particular gadget or appliance”. As per Table 2, that definitional change has parallel effects on the skills sought by the industry now. Traditional skills seem to trend down and are less determinant for gaining jobs in the last decade (PayScale, 2017).

The U.S. case is similar to changes in U.K. 20 years earlier, when the latter needed new competencies for business and innovation due to globalisation (Figure 6). Tony Blair's government established a Creative Industries Task Force (CITF) in 1997. It included industrial design in an array of economic activities to generate knowledge and exploit creativity as the ultimate economic asset. Leading U.K. thinkers coined new terms such as the 'creative economy' that placed capital value on knowledge workers' novel imagination instead of traditional forms of capital, such as property, labour, and input-output production (Howkings, 2001). In addition, the Design Council U.K. promoted their Creative Britain agenda (Cox, 2005; Design Council, 2005). Echoing that change, Deloitte elaborated recently a four-competencies model with skills needed by designers today, as shown in Figure 7 (Deloitte, 2015).

Ranking carried out for this research showed 96 U.S. universities and colleges contained some kind of design content. Specifically, 64 had specific industrial design courses (30 undergraduate, 30 undergraduate and postgraduate mix, 4 postgraduates only). U.S. Design courses are accredited by the National Association of Schools of Art and Design. Yet, not all schools adhere to it, nor disclose information about them. Only 40 were IDSA registered (Industrial Designers Society of America, 2014). Curricula, teaching approaches and outcomes highlighted divisions between engineering and artistic perspectives that suffered a shake-up a decade ago. Subsequently, several design schools redefined their role and agency. Before 2007-2008 Global Financial Crisis (GFC), many programs failed students for not gaining real design process education. Often, engineering programs claimed to be design ones. Students learned design thinking which lacked insights from cultural, aesthetic and form intelligence. Most graduate portfolios showed 3D CAD and model-making skills missing creativity (Amit, 2010).

U.S. education post-GFC started to change, filling the gap between traditional education and market expectations, and to address complex and yet undefined social and technology challenges. Surveys from 2009 onwards demonstrated a significant shift in education and industry concerns. As per grey highlighting in Tables 3 and 4, approximately the same design courses remained in the top 10 list in the last decade after cross-referencing data among Deans, Department Heads and experts' views from 2,237 firms and organisations. Signature programs led by cooperation, participatory design, integrative design that extended onto HCI and service design, well rounded and trans-disciplinary programs, design maturity, advocacy, technical strengths, flexible curriculum, learner and user-based design, strategy, research and methods, theory, industry ties and sustainable design practice. Their approach also positioned them among leading programs at international level (Design Future Council, 2009, 2013, 2014, 2016; Graphiq, 2017; PayScale, 2017; Q. S. Top Universities, 2016, 2017; U.S. Bureau of Labor Statistics, 2017b; U.S. Department of Labor, 2017).

Table 2: U.S. skills trends affecting salaries for industrial designers as per PayScale (2017)

Trend	Skills	Trend	Skills
▲ 12%	Project Management	▼ 0%	Adobe Photoshop
▲ 11%	Engineering Design	▼ 1%	SolidWorks
▲ 4%	Concepts and Standards	▼ 2%	3D Rendering
▲ 3%	Computer Aided Design (CAD)	▼ 3%	Graphic Design
▲ 2%	Design	▼ 3%	Adobe Illustrator
▲ 2%	Product Development	▼ 3%	AutoDesk
		▼ 3%	3D Printing
		▼ 5%	AutoCAD

Note. Reprinted from PayScale, 2017, Industrial Designer Salary, by PayScale Human Capital, retrieved from https://www.payscale.com/research/US/Job=Industrial_Designer/Salary, Copyright © 2018 PayScale, Inc.

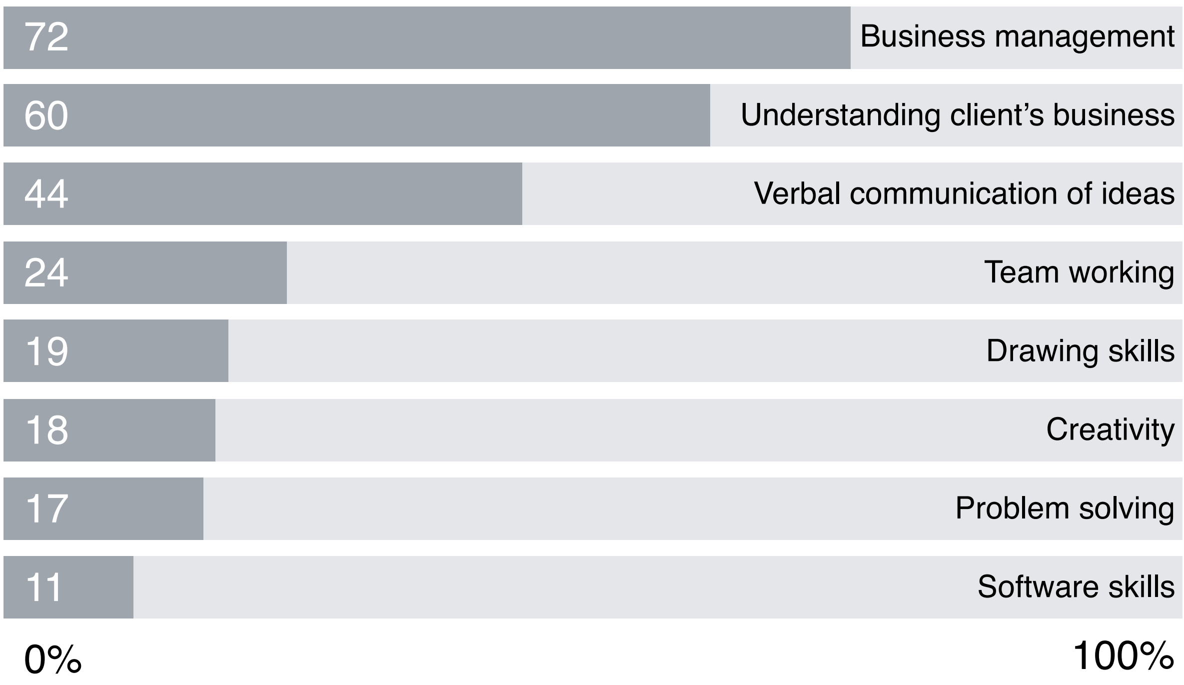


Figure 6: U.K. skills designers lack the most. Reprinted from Design Council, UK, 2005, The Business of Design: Design Industry Research in 2005, retrieved from www.designcouncil.org.uk, Copyright © 2005 Creative Commons.

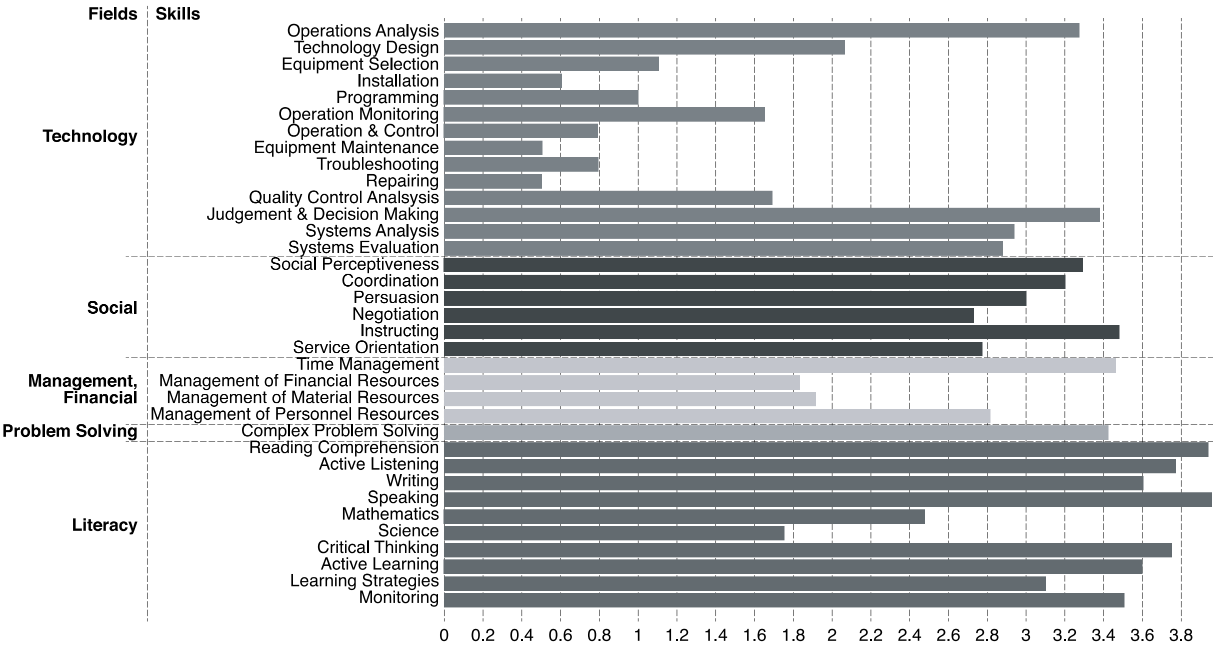


Figure 7: Critical skills for jobs employing industrial designers. Reprinted from Deloitte, 2015, Industrial & Product Design, Data USA, retrieved from https://datausa.io/profile/cip/500404/, Copyright © GNU Affero General Public License v3.0 (GPLv3).

Two design schools often in the top 2 positions in the last decade were significant in understanding the shift needed for modern design education. Rhodes Island School of Design (RISD) was awarded the 2011 Forbes Best School after changing their traditional and analogue course to incorporate digitalisation, *critical making* (hands-on object-oriented process that merges physical and digital exploration and promotes conceptualisation and shared acts of making instead of focusing on evocative objects), and STEAM (science, technology, engineering, arts and design, mathematics) in 6 years. STEAM upgraded STEM (science, technology, engineering, mathematics) that had difficulty translating skill into creative innovation (Guyotte, Sochacka, Costantino, Walther, & Kellam, 2014; 2015; Maeda, 2012; Somerson & Hermano, 2013).

The Carnegie Mellon program defined the 21st century need to transition towards a sustainable society within a globally interconnected and interdependent world. A multi-year change process transformed academic culture based on a new pedagogical framework of design iterations and making of artefacts spanning among the built, social and natural worlds. Three design tracks were offered: product, communications, and environments. The latter recognised that the previous two now happen together in physical and digital spaces and ecologies. Consequentially, students had the choice of customising pathways that focused on a continuum of design approaches: service, social innovation and transition. They were encouraged to shift focus from products to quality of interaction and experiences, social, cultural and economic problems, and to research and speculate long term vision to reformulate lifestyles and society’s infrastructure (policies, energy resources, transport, manufacturing, economy and food, healthcare, and education systems), develop new mindsets, theories and ways for designing and change (Irwin, 2015; Irwin, Tonkinwise, & Kossoff, 2013).

The comparison of U.S design programs overall revealed a complex array of offerings and setups; nevertheless, official rankings were not always complete. On the one hand, leading programs were neither purely engineering nor art focused. Instead, they intended to build design as a solid innovation-driven discipline with transdisciplinary collaboration, user-centred, participatory and meaningful research. On the other, several traditional programs ranked high and attracted many students based on institutional reputation. Data, as per Figure 8, indicated that U.S. online real-time job market prospects shown to the public still profiled conventional pathways for the profession (PayScale, 2017).

There was an oversupply of U.S. graduates for an industry that was ahead of education, but that was still not catching up with the effects of globalisation and technology. 2015 surveys showed 1,819 new graduates that year, with expectations of graduate growth of 2% per year in an industry of 38,400 industrial designers, and only 800 further jobs offers by 2024. Course fees also affected students' access, performance and job prospects depending those were private or public (e.g. education, institutional assets investment per student). Ideal students-to-teacher ratio showed as 12:1 to 15:1 for project-based learning and critical thinking. Private courses had an average of 13:1 with a minimum of 3:1. All ratios in the public-sector courses were too high, averaging at 18:1 with margins between 16:1 and 27:1. Internationally, four courses ranked 10 bests, eleven in the 11-50, and eight among the 51-100 ranking. U.K. Quacquarelli Symonds showed leading U.S. and European courses now compete against upcoming Asian offerings; this is a sign that education, industry and innovation are no longer the patrimony of first world countries.

International benchmarks revealed the need to transform mindsets and to close skill gaps in an Australian context that is characteristically conservative but that needs to compete in a globalised market. It is noteworthy that the Australian Bureau of Statistics (ABS) classified industrial design as "technical commerce" together with fashion and jewellery in 2006 (ANZCO 232312). The ABS still embeds it with mass and batch production saying designers "plan, design, develop and document industrial, commercial or consumer products for manufacture with particular emphasis on ergonomic factors, marketing and manufacturability" (Australian Bureau of Statistics, 2015). Recently, the proposal of industrial design within the creative industries followed overseas trends. However, education and professional practice need to reshape to achieve that goal. Professional and state bodies have not changed much in the last 20 years.

Table 3: 2017 U.S. industrial design courses and majors ranking (a)

	Name	SC	QS	QS Ranking	QS5	DI D UG	DI D G	DI Q	SC R	Accept (%)	Grad (%)	S2T Ratio	Pub	Priv (NFP)	Priv (FP)
1	Massachusetts Institute of Technology (MIT)		*	2	5+				3	8.3	93	3		*	
2	School of Art Institute of Chicago (SAIC)		*	7				BM	NR	66.5	54	9		*	
3	Yale University		*	8	5+		3		2	NR	NR	12			*
4	California Institute of the Arts (CalArts)		*	12					NR	24.9	57	7		*	
5	New York University (NYU)		*	22					101	32.1	84	10		*	
6	University of California, Los Angeles (UCLA)		*	13					33	17.3	90	16	*		
7	Columbia University, New York		*	24	5+				3	6.6	94	25			*
8	School of Visual Arts New York (SVA)		*	25					NR	75.3	65	9			*
9	Princeton University		*	34	5+		15		13	7	97	11		*	*
10	University of Southern California		*	46					11	20	50	29			*
11	University of Chicago		*	49	5+				15	8.4	88	6			*
12	Brown University		*	51-100					17	9.5	84	9			*
13	Cornell University		*	51-100	5+				20	15.1	93	9			*
14	Cranbrook Academy of Art, Bloomfield Hills, MI		*	51-100				M	NR	NR	5.7	NR			
15	Maryland Institute College of Art		*	51-100					NR	47.4	73	9			*
16	Savannah College of Art and Design		*	51-100					NR	69.9	68	20			*
17	University of California, San Diego (UCSD)		*	51-100					58	33.7	86	19	*		
18	University of Michigan		*	51-100	5+			BM	36	26.3	90	12	*		
19	University of Pennsylvania		*	51-100	5+			M	9	10.2	96	6			*
20	Virginia Commonwealth University		*	51-100					NR	79	57	17	*		
21	Illinois Institute of Technology, Chicago		*				3	M	150	52.7	63	13			*
22	Art Institute of Colorado, Denver		*					B	NR		35	18			*
23	Southern Illinois University Carbondale		*					B	NR	80.6	44	21	*		
24	University of Notre Dame Indiana		*					BM	18	19.8	95	10			*
25	Kansas State University Ames		*					BM	NR	94.9	60	19	*		
26	Kendall College of Art and Design, Chicago, IL		*					B	NR	74.4	28	8			*
27	Northern Michigan University Marquette		*					B	NR	69.9	48	21	*		
28	Wayne State University Detroit		*					BM	NR	79.9	32	16	*		
29	New Jersey Institute of Technology		*					B	310	60.8	58	17	*		
30	Stanford University Stanford, California	*		8	5+				4	5.1	95	10		*	
31	Georgia Institute of Technology Atlanta, GA	*				5		BM	48	33.4	79	18	*		
32	Carnegie Mellon University Pittsburgh, Pennsylvania	*		13		3	1	BM	52	24.6	87	10		*	
33	University of Illinois, Urbana-Champaign Champaign, IL	*		51-100				BM	70	59.0	84	19	*		
34	University of Washington-Seattle Campus Seattle, DC	*		51-100				BM	86	55.2	81	18	*		
35	Brigham Young University-Provo Provo, UT	*						B	94	47.0	77	18		*	
36	Ohio State University-Main Campus Columbus, OH	*		51-100	5+			BM	102	53.0	82	18	*		
37	Syracuse University Syracuse, NY	*				5			126	53.2	82	16		*	
38	Purdue University-Main Campus West Lafayette, IN	*						BM	129	59.3	70	12	*		
39	Clemson University Clemson SC	*							131	51.5	82	16	*		
40	Virginia Polytechnic Institute and State Uni. Blacksburg	*						B	142	72.6	83	16	*		
41	North Carolina State University at Raleigh, NC	*						BDM	146	51.6	71	16	*		
42	Iowa State University Ames, Iowa	*						B	214	86.9	71	19	*		
43	Rhode Island School of Design Providence, Rhode Island	*		3		2	3	BM	215	32.6	86	10		*	
44	University of San Francisco San Francisco, California	*							235	60.1	67	14		*	
45	Auburn University Auburn University, Alabama	*						BM	254	83.5	68	17	*		
46	University of Utah Salt Lake City, Utah	*						B	261	81.4	59	17		*	
47	Cedarville University Cedarville, Ohio	*							277	74.5	72	13		*	
48	Arizona State University-Tempe Tempe, Arizona	*		51-100				M	280	84.3	58	22		*	
49	University of Illinois at Chicago, Illinois	*						BM	312	74.5	58	17	*		
50	Rochester Institute of Technology Rochester, New York	*						BM	323	57.5	63	13		*	
51	California State University-Long Beach Long Beach, CA	*						BM	330	35.5	57	25	*		
52	Appalachian State University Boone, NC	*						B	359	62.7	66	16	*		
53	Drexel University Philadelphia, PA	*						B	367	76.0	65	10		*	
54	University of Houston, TX	*						BM	393	63.0	46	22	*		
55	Western Washington University Bellingham, WA	*						B	400	84.6	67	19	*		
56	University of Kansas Lawrence, KS	*						BM	404	91.4	64	17	*		
57	University of Cincinnati-Main Campus Cincinnati, OH	*		51-100		1	5	B	444	75.8	62	18	*		
58	San Jose State University San Jose, CA	*						B	453	59.9	47	27	*		
59	The Art Institute of California-Argosy University Orange County Santa Ana, CA	*						B	NR	98.2	36	17			*
60	The Art Institute of California-Argosy University Hollywood North Hollywood, CA	*							NR	64.4	27	18			*

Note. Data for industrial design courses rankings from U.S sources as per Design Future Council (2009, 2013, 2014, 2016), Graphiq (2017), PayScale (2017), U.S. Bureau of Labor Statistics (2017b), U.S. Department of Labor (2017), and Europe as Q. S. Top Universities (2016, 2017).

Table 4: 2017 U.S. industrial design courses and majors ranking (b)

	Name	SC	QS	QS Ranking	QS5	DI D UG	DI D G	DI Q	SC R	Accept (%)	Grad (%)	S2T Ratio	Pub	Priv (NFP)	Priv (FP)
61	Pennsylvania College of Technology Williamsport, PA	*							NR	NR	40	18	*		
62	Universidad Del Turabo Gurabo, PR	*							NR	46.0	16	40		*	
63	Escuela de Artes Plasticas de Puerto Rico San Juan	*							NR	92.7	27	13	*		
64	University of Wisconsin-Stout Menomonie, WI	*						B	NR	90.8	52	20	*		
65	Milwaukee Institute of Art & Design Milwaukee, WI	*						B	NR	59.1	55	10		*	
66	Walla Walla University College Place, WA	*							NR	57.8	50	13		*	
67	The Art Institute of Seattle, WA	*						B	NR	51.3	30	19			*
68	The University of the Arts Philadelphia, PA	*						BM	NR	69.6	57	8		*	
69	Philadelphia University Philadelphia, PA	*						BM	NR	63.9	61	13		*	
70	The Art Institute of Pittsburgh, PA	*							NR	50.9	44	15			*
71	The Art Institute of Philadelphia, PA	*							NR	46.6	35	15			*
72	The Art Institute of Portland, OR	*						B	NR	87.8	29	14			*
73	Columbus College of Art and Design Columbus, OH	*						B	NR	88.6	55	12		*	
74	Cleveland Institute of Art Cleveland, OH	*						B	NR	67.0	60	9		*	
75	SUNY Buffalo State Buffalo, NY	*							NR	61.6	48	16	*		
76	Pratt Institute-Main Brooklyn, NY	*		6		5		BM	NR	53.0	65	8		*	
77	The New School New York, NY	*		4				BM	NR	65.9	65	10		*	
78	Fashion Institute of Technology New York, NY	*							NR	44.3		17		*	
79	Montclair State University Montclair, NJ	*						BM	NR	66.8	63	17	*		
80	Kean University Union, NJ	*						B	NR	70.4	50	17	*		
81	Lawrence Technological University Southfield, MI	*							NR	57.4	52	11		*	
82	Ferris State University Big Rapids, MI	*							NR	78.4	53	16	*		
83	College for Creative Studies Detroit, MI	*						BM	NR	45.6	57	9		*	
84	Wentworth Institute of Technology Boston, MA	*						B	NR	82.6	64	16		*	
85	Massachusetts College of Art and Design Boston, MA	*						B	NR	72.9	65	9	*		
86	University of Louisiana at Lafayette, LA	*						B	NR	55.8	44	23	*		
87	Columbia College-Chicago, IL	*						B	NR	88.5	41	13		*	
88	Savannah College of Art and Design Savannah, GA	*				5		BM	NR	66.6	65	19		*	
89	The Art Institute of Fort Lauderdale Fort Lauderdale, FL	*						B	NR	52.1	39	20			*
90	University of Bridgeport, CT	*						B	NR	60.7	32	17		*	
91	Metropolitan State University of Denver, CO	*						B	NR	65.1	25	19	*		
92	San Francisco State University San Francisco, CA	*						BM	NR	66.0	47	24	*		
93	Otis College of Art and Design Los Angeles, CA	*						B	NR	66.5	53	7		*	
94	California College of the Arts San Francisco, CA	*		28				BM	NR	63.7	45	9		*	
95	Art Center College of Design Pasadena, CA	*		19		3	1	BM	NR	80.9	70	9		*	
96	Academy of Art University San Francisco, CA	*						BM	NR	NR	32	16			*

Nomenclature							
DI:	US Design Futures Council -Design Intelligence (DI): Deans Survey on Best Industrial Design Undergraduate Courses						
QS:	UK Quacquarelli Symonds (QS) World University Ranking by subject from 76,798 academics opinions and scanned 28.5 million research papers						
QS5:	QS 5 Stars: Maximum ranking in Research, Teaching, Internationalization, Specialist Criteria, Employment, Facilities, Innovation, Inclusiveness						
SC:	StartClass RankSmart is based on academic excellence, admissions selectivity, career readiness, financial affordability, and expert opinion (US News, Forbes, and more)						
DI UG:	Deans Survey Undergraduates	**DI G:**	Deans Survey for Graduates	**DI Q:**	Qualification Granted		
SCR:	StartClass Ranking	**Accept:**	Acceptance Rate	**Grad:**	Graduation Rate		
S2T:	Student to Teacher Ratio	**Pub:**	Public	**Priv:**	Private	**NFP:**	Non-for Profit
				FP:	For Profit		
B:	Bachelor	**M:**	Masters (including Postgrad)	**NR:**	Not Rated		

At last count, 2,925 industrial designers were mainly concentrated in New South Wales (990, 33.8%) and Victoria (1,223, 41.8%). 362 registered companies (12 more after a decade) employed 1,725 designers (10 average per firm). Major markets were packaging (32%), commercial infrastructure (21%), home goods (19%) and consumer goods (16%). However, the two main employment sectors, manufacturing (49%), and professional, scientific and technical services (32.8%), have trended down for 30 years. National manufacturing's GDP plummeted by 2013 (6.8%). A further drop is expected following the 2017 car industry shut down (5%) which has impacted mainly Victoria (200, 15%). High-tech exports (2.3%) are not filling the void as several companies have left the country.

Other fields of employment, like retail (8%) and construction (3%), do not show significant change (Andersen, Ashton, & Colley, 2015; Australian Bureau of Statistics, 2013, 2017; Cahill, 2010; Creative Industries Innovation Centre, 2015; Cully, 2016; Dixon, 2013; Dos Santos Duisenberg, 2010; Labour Market Information Portal, 2017; Roberston, 2013a, 2013b; G. Roos, 2012; Wright, Davis, & Bucolo, 2013). Academically, 29 universities and technical and further education institutions (TAFE) deliver design content. Universities offered 14 Bachelors, 5 Masters, 6 PhD courses specifically. One university's course made the top 25, and five universities had the 50 best Bachelors in world rankings. Graduations are unregulated and increasing over a shrinking market demand, despite statistical estimates of 2% per year growth and forecasts of 800 more new jobs by 2020 (Australian Bureau of Statistics, 2013). Industry and academic experts who were interviewed during the project recommended redefinition, since education did not clearly teach new competencies to compete internationally. Accordingly, several courses have changed to names such as 'product innovation' and 'integrated product design' (BachelorsPortal, 2017; HotCourses, 2017a, 2017b, 2017c, 2017d; Q. S. Top Universities, 2016; StudyPortals, 2017; University of South Australia, 2017).

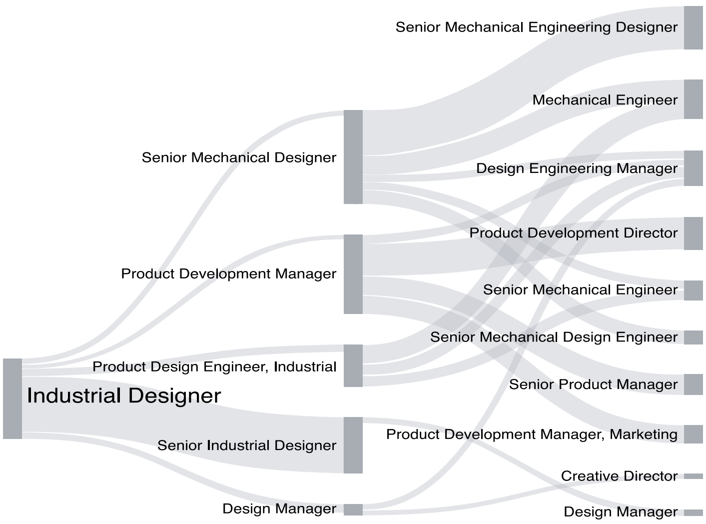


Figure 8: U.S. traditional pathways for industrial designers. Reprinted from PayScale, 2017, Industrial Designer Salary, by PayScale Human Capital, retrieved from https://www.payscale.com/research/US/Job=Industrial_Designer/Salary, Copyright © 2018 PayScale, Inc.

Digitalisation Benchmark

Curriculum development also needs to deal with disruptive technologies, such as ICT. Design education should be well suited for digitalisation since its participants are thought of as innovators. However, the education business in general has proven slow to adapt to digitalisation. Often top-down management buys quickly into these types of infrastructure investment, while academics in *abandoned, soft* and *hard-centre* learning models may be reluctant to change. Inertia against technology adoption follows a model that has seen higher education rarely disturbed by innovation for 100 years. Still, the impending change follows a known pattern. Expertise does not necessarily lose to better replacement, but cheaper and simpler know-how that later improves and displaces the incumbent (Christensen & Eyring, 2011). Meanwhile, students are generally thought as digital natives who are comfortable with change. Yet, international research demonstrates higher digital use does not necessarily equate to innovative learning (Carneiro, 2011).

Using the U.S as a benchmark, university-wide multi-year studies such as Chen, Seilhamer, Bennett, and Bauer (2015) revealed students' mobile technologies in education generally turn into greater social networking, music, social media, navigation, entertainment, photography and games, for above-learning use (Figure 9). Similar in Australia, our university supported digitalisation of learning and mobile technologies. It is worth mentioning a 2012-2015 iPad project for all first-year students that has now converted to a BYOD (acronym for Bring Your Own Device) initiative (Kirkpatrick, 2017; Russell, 2014; Russell & Jing, 2013). By 2017, students had greatly shifted to mobile and online use alongside up-surging devices like iPads (Figure 10). The data did not specify learning quality though, while registering hit rate for access to apps and information. Still, it is indicative that social networking, teacher vodcasting and web sharing increased. Otherwise, digital tools use that lean towards active learning and communication, such as lecturer-student emails exchange, making web pages, blogs, virtual worlds and sims, stayed the same or diminished (Figure 11).

Research is gradually uncovering shortcomings of a global rave for digitalisation in favour of massification of learning and economies of scale. Older generations do not adopt and use new technology at the rate expected, while younger generations, Millennials and Generation Z (GenZ), communicate with mobile consumer-like tools but find difficulties working at higher-level thinking. Digitalisation is changing their capacity to think, read, store, recall and convert information into knowledge (Allen, 2015). Bettinger and Loeb (2017) discovered many students fare worse through online learning than traditional classes, since they cannot follow process, take action or elaborate deep meaningful reasoning (Carr, 2011). Microsoft measured increasing media consumption, digital lifestyles and multi-screening decreases users' ability to focus, learn and filter distractions by an average of 8 seconds (Gausby, 2015). Deloitte Touche Tohmatsu (2017) also found cultural gaps among digital natives. Millennials said GenZ are less prepared (e.g. experience, patience, maturity, integrity) and need to be humble, willing to learn and work hard.

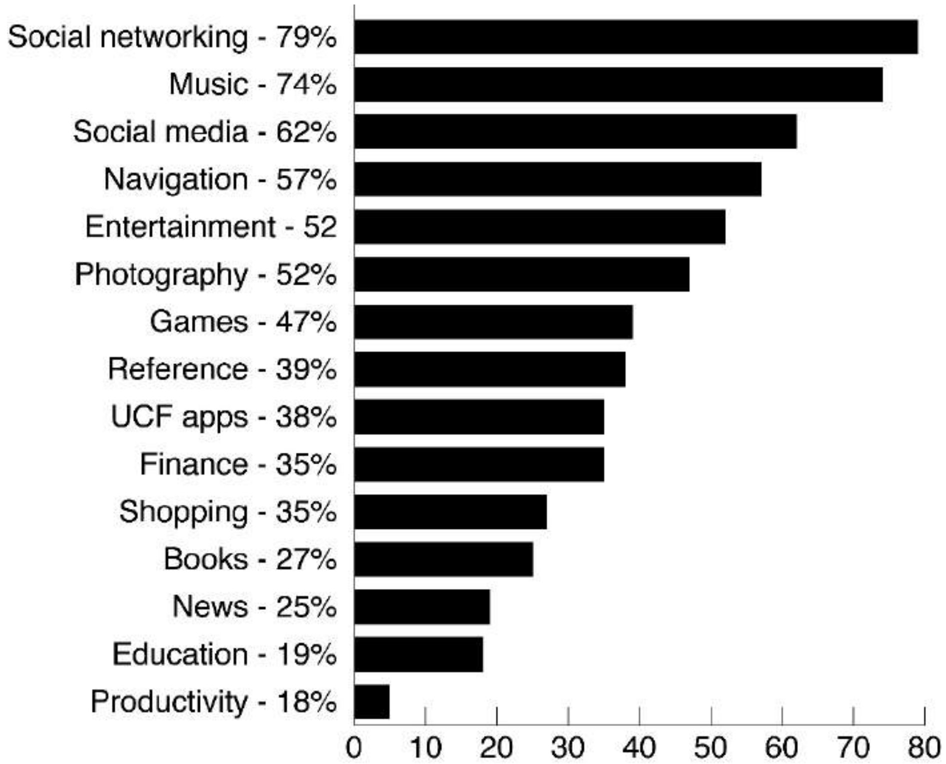


Figure 9: 2012-2014 University of Central Florida most popular personal app use per category (N=1,181). Reprinted from Chen, Baiyun, Seilhamer, Ryan, Bennett, Luke, & Bauer, Sue. (2015), Students' Mobile Learning Practices in Higher Education: A Multi-Year Study. Educause Review, 7.

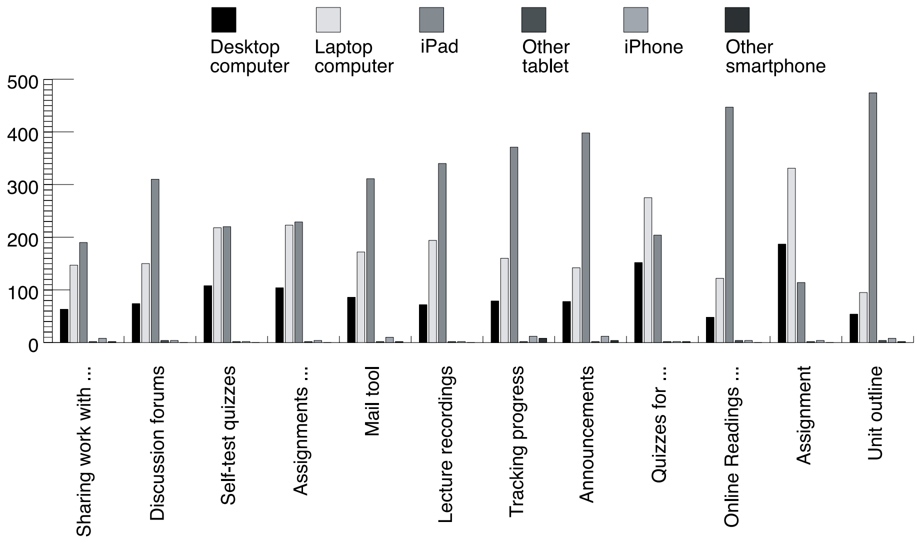


Figure 10: Students shift to mobile devices Reprinted from Kirkpatrick, Denise. (2017), Learning and Teaching: Digital Strategies and Enabled Environments, Keynote presented at the University of Canterbury's Teaching Week Christchurch, New Zealand.

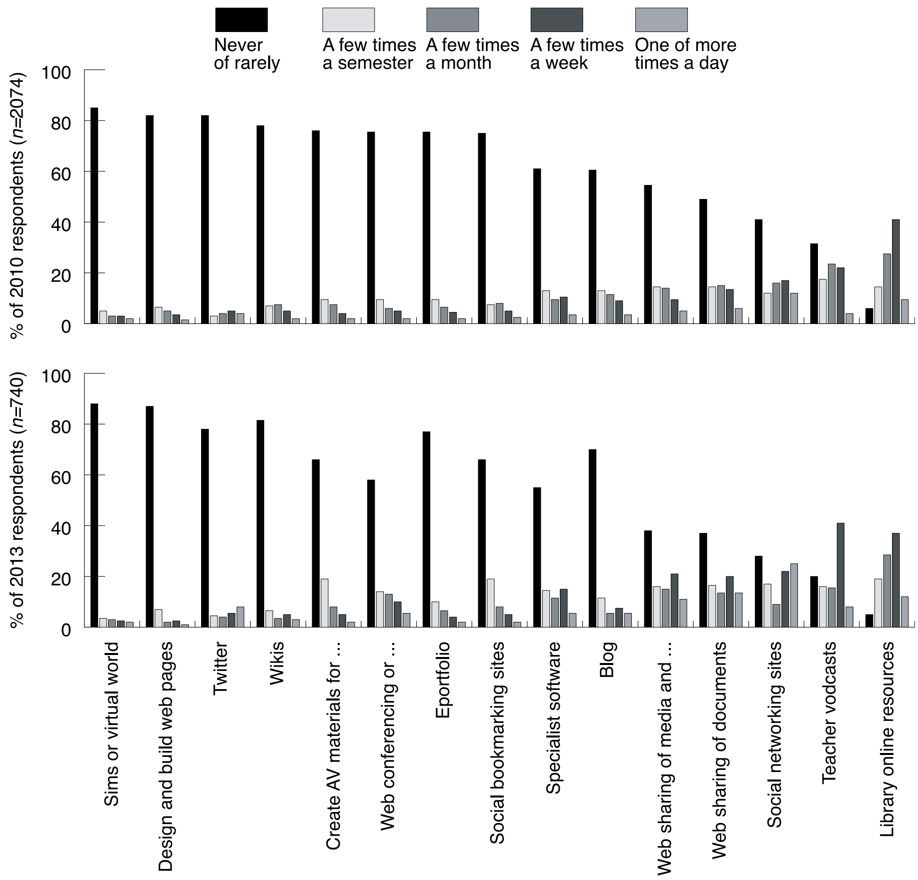


Figure 11: 2010-2013 Frequency of online study activities Retrieved from Russell, Carol. (2014), Herding Cats And Measuring Elephants: Implementing And Evaluating An Institutional Blended And Mobile Learning Strategy. Rhetoric and Reality: Critical perspectives on educational technology, 211-221, Copyright © 2013 Christopher Allan, Mark Symes, and Jill Downing

New Curriculum

The Australian circumstances of the course redesign were unique. A new curriculum needed to address the industrialisation and declining of education standards, digitalisation and globalisation while capitalising on academics' traditional skills, students' cultural-historical background, and design capacity to trigger social construction of knowledge by promoting participants' adaptable elastic mind and imagination (Antonelli, 2008). Assessing students' skills and incumbent teaching models were critical to comprehending the potential and obstacles that might influence design intervention and adoption of a new curriculum.

Analysis of students interviews and outcomes from first year onwards revealed that their array of skills and retention rate (close to 50% rate) echoed those of larger national and international assessments. The OECD Program for International Student Assessment (PISA) and Australian National Assessment Program - Literacy and Numeracy (NAPLAN) data revealed a decrease of STEM skills coming from high-school regardless of high or low performers. This is at a time when 75% of the fastest growing occupations require STEM skills (Ainley & Gebhardt, 2013; Australian Industry Group, 2015). Higher education was rigid because slight customisation meant high bureaucratic cost (Corneli & Danoff, 2011). The Australian uncapping of supply of Commonwealth-supported places (CSPs) in universities made it difficult to keep cohort equity because there was no longer a minimum skill set on the low performers' side (Harvey, 2016). The cohort was characterised by more than 100 ethnicities, with 62% being first in a family at university, 39% speaking a different language at home, and 27.9% being from low socio-economic status (Centre for Western Sydney, 2017).

The industrial design curriculum was also a mix of teaching models. The program had strong institutional *universal* preconditioning based on Bloom's taxonomy (*hard-centre)*, whilst academics handcrafted teaching based on technical skill transmission (*abandoned-centre)* that replicated traditional disciplines. All students' needs, interests and abilities were treated the same (Twigg, 2003) in a manner of social reproduction that maintained pervasive inequalities. The lecturer-to-student ratio was 1:25 officially. However, classes were often run with 1:30 or more. Instruction was greatly based on general knowledge (e.g. materials sciences, ergonomics, 3D CAD drafting) and assumptions on design's final users and market. The course only ventured into initial design inquiry and practice-based research in the final semester of the course.

A behavioural, cultural and epistemological break was needed to enable a curriculum change based on practice and object-oriented social construction of knowledge. Bourdieu helped in contextualising design education as practical logic that allows habitus to escape from a subject-object dichotomy through free choice (agency). Habitus means the internalised social system of being, seeing, acting and thinking since young age. A plurality of views was key to learning how to deal with the uncertainty of power play and social position within the design program (Bourdieu, 1984, 1990; Bourdieu & Biggart, 2002; Bourdieu & Passeron, 1990). Design agency needed to avoid intellectual bias that objectifies participants and requires undisputed acceptance of traditional good design and aesthetics definitions (taste). This was no easy task as incumbent mechanisms tried to keep status quo. Nonconforming individuals risked alienation. Consequently, academic reproduction risked failing the design imperative of leading by innovation. Participants deserved to reprise design learning and innovation as three types of capital: academic capital as a new discourse based on continuity among practice and theory; cultural capital to embody social and symbolic assets (e.g. authority, education, goals, qualifications, taste); and design capital by *redesigning* curriculum through

1. Renovating attitudes, behaviour and skill,
2. Allowing predisposed influences into the learning experience (e.g. outside experiences, family, relations),
3. Avoiding inequalities and academic divisions (e.g. lecturer, student), and
4. Promoting a new culture of learning.

Socio-cultural benefits would come from a collaborative community that raised the bar from skills to competencies (know-how collections) and convert all participants into engaged practitioners in joint enterprises, shared repertoires and transdisciplinary integration. Learning by tinkering was to help develop a new learning environment based on playing with artefacts and data to find new information, building knowledge, fostering imagination, creativity, peer-to-peer (P2P) sharing, and open networking (Engeström, 2013; Thomas & Brown, 2011).

ASA clarified social construction of knowledge complexity when placing participants (academics, institution, students), internal and external scenarios in the same space-time paradigm. Rules, outcomes, objects and divisions of labour depended on social positions. The institution applied infrastructure and management measures aiming to precondition competitiveness, excellence and profit. Academics focused on keeping graduation numbers up to protect their course survival and saw top-down administration and application of technology as interference (e.g. campus relocations, ICT). Students had limited understanding of benchmarks on design, education, and industry excellence. Therefore, they normally fitted to status quo, believing that was the best way to obtain good qualifications and future employment. As per Engeström (2008), these were opposed, rather than shared views, that unleashed *runaway objects* that either hindered participants' outcomes if interference was dictated and unexplained, or encouraged them into meaningful learning if they were able to contextualise and participate in that disruption (Figure 12). Therefore, the ASA analysis revealed that a foundational base was needed, for:

1. Continuous leadership to shift from old to up-to-date design education;
2. Periodic ASA snapshots on process (semester and year to year diagnosis), based on specific space (the interval between artefacts) and time (the interval between events);
3. Building common ground for collaborative activity among participants (academics, institution, students) to facilitate radical emancipatory possibilities for design education.

Hence, small exemplars with participants were developed (e.g. assessments, units) to later apply to larger curriculum change. Students and academics forums were held over three years. Participants built capacity from insight, imagination and foresight. Eight curriculum advisors, industry experts and an external advisory committee contributed. Students were open to curriculum reformulation. They noticed differences between the old course and their everyday experiences. Interestingly, two thirds of academics saw no need for change. Then, one third proposed changing back to artistic illustration. Another wanted more 3D CAD drafting. Both views echoed national shortcomings, regarding translation of education investment to innovation, that believe teaching is about transmitting operational skills instead of building new knowledge (Innovation and Science Australia, 2017). A last group believed the course missed the increasing convergence between design and algorithms, bioengineering, cybernetic intelligence, computer sciences, cultural studies, HCI, ICT, user experience (UX), and HCD since 1960s electronic age (Brand & Rocchi, 2011; Cross, 1993; Overbeeke & Hummels, 2014).

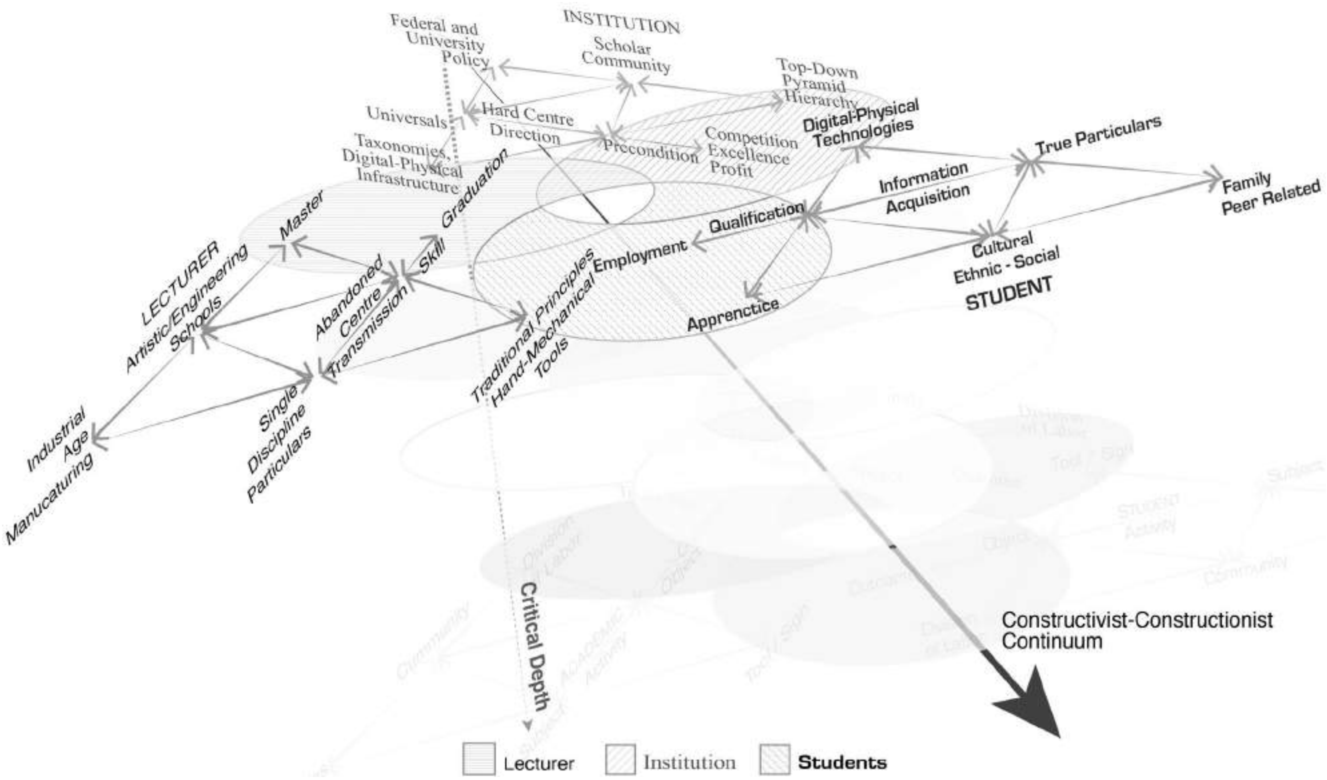


Figure 12: Participants' ASA evaluation within space-time paradigm. Reprinted from Author, 27 October 2014, Industrial Design Curriculum 2016: New Vision and Imperative, Unpublished internal document.

A vision and mission were written for the first time for the course to assist participants to *collaboratively bring up creativity, innovation and entrepreneurship* into our School of Computing, Engineering and Mathematics which has 22 undergraduate and 18 graduate courses. Participants had to become *independent all-rounders working responsibly, sustainably and transdisciplinary to add value to users, society and industry in today's creative economy*. Curriculum renewal followed Bauhaus, HfG Ulm, Malmö, and recent manifestations of open school movement. It took Dewey's learning-by-doing further to Papert's constructionism (situated project-based learning building and internalising new knowledge) and Brown's entrepreneurial learner who knows by finding and evaluating (*homo sapiens*), learns by building content and context hands-on (*homo faber*) and creates new culture by playing and experimenting (*homo ludens*) with lateral thinking and feeling, not just logical calculus (Brown, 2013; Harel & Papert, 1991; Papert, 1986).

The new curriculum aligned with critical pedagogy through *critical design and making* as *material speculations* that reconnect conceptual, linguistic, physical and digital acts of knowing, discussing and thinking with artefacts (Freire, 1970; Wakkary, Odom, Hauser, Hertz, & Lin, 2015). *Critical design* prototyped artefacts that challenged everyday reinforcing of status quo (*affirmative design*) to query product optimisation and social norm (Dunne, 1999; Dunne & Raby, 2001). *Critical making* by iterative prototyping witnessed a constructionist process reconnecting critical thinking (abstract, explicit, cognitive, linguistic) with material, tacit, embodied, external and community-oriented making (Ratto et al., 2011; Ratto & Hockema, 2009). Computers were intervened with coding and physical intervention more than just using them as consumer-like tools (e.g. MS Word, Photoshop, SolidWorks). STEAM supported CDIO (conceiving, designing, implementing, operating) framework that validated design by proving it works practically (use, adoption). Instead of accepting design as completed and successful at concept proposal stage (conceiving), as had been done previously.

Transition into the new program was staged progressively and the curriculum was inverted. As an example, a new unit called *Contextual Inquiry* replaced and moved the only third year design research unit in the old course to first year and semester with the name *Introduction to Industrial Design Methods*. Likewise, the course's Design Studio stream increased from 4 to 6 units that now started in the first year and semester instead of the second year. Students had to build a fresh discourse that helped in working out their predisposed influences through applied research and tinkering from first day in the course. Design value relied on openly identified, discussed and accepted knowledge that has specific history, culture, people status and available technology. Lecturers and students started with what they knew, to later dive deeper and solve social and technology relations. Then, they enabled users and themselves to mix and create new experiences and projects through bottom-up maker, hacker culture, and networked platforms independent from traditional experts (Lessig, 2008). The new course contained a curriculum structure three-dimensionally wrapped around a digital spine called Lab Space (Figure 13, Table 6), that connected all levels of critical depth represented horizontally (technical skill), vertically (length of schooling), diagonally (social construction of a continuum of constructionist-constructivist learning). It also capitalised on digitalisation and P2P through:

- Maker Hub (Makerspace, Hackerspace, FabLab, TechShop)
- Individual ePortfolios as open reference on progress from first-year
- Industry projects increasing in complexity from first year
- Design Factory model-like in senior years intending to bring together researchers, students, industry partners and entrepreneurs in working integrated learning approach to solve complex challenges (Aalto University, 2008).

Specifically, ePortfolio was chosen as a constructionist digital instrument to assist changing students' habitus. They would use it as a learning space to gather and share information, recall memory, ideate, research, and develop new design narratives through heuristic prototyping and experimentation. This researcher sought university funds for this as a project; it grew to supporting a three schools pilot from 2012 to 2014 (Table 7). The University chose Pebble+ platform since it worked as Blackboard add-on. Pebble+ allowed scaffold learning as active reflection and presentation, private and networked sharing, discussion and feedback. Pilot Schools had different views about ePortfolios. Subsequently, two of the Schools dropped out. They treated ePortfolios either as basic Dropbox file repositories or as online MS Word processing (e.g. essays, CV file attachments). Students found ePortfolios unintuitive, confusing and unfriendly since templates, rubrics and text formatting were difficult, and became reluctant to use them. They frequently lost their unsaved essays while trying to format work live without saving (Blom, Rowley, Bennett, Hitchcock, & Dunbar-Hall, 2013; Mason, Langendyk, & Wang, 2013; Rowley, Bennett, & Blom, 2014).

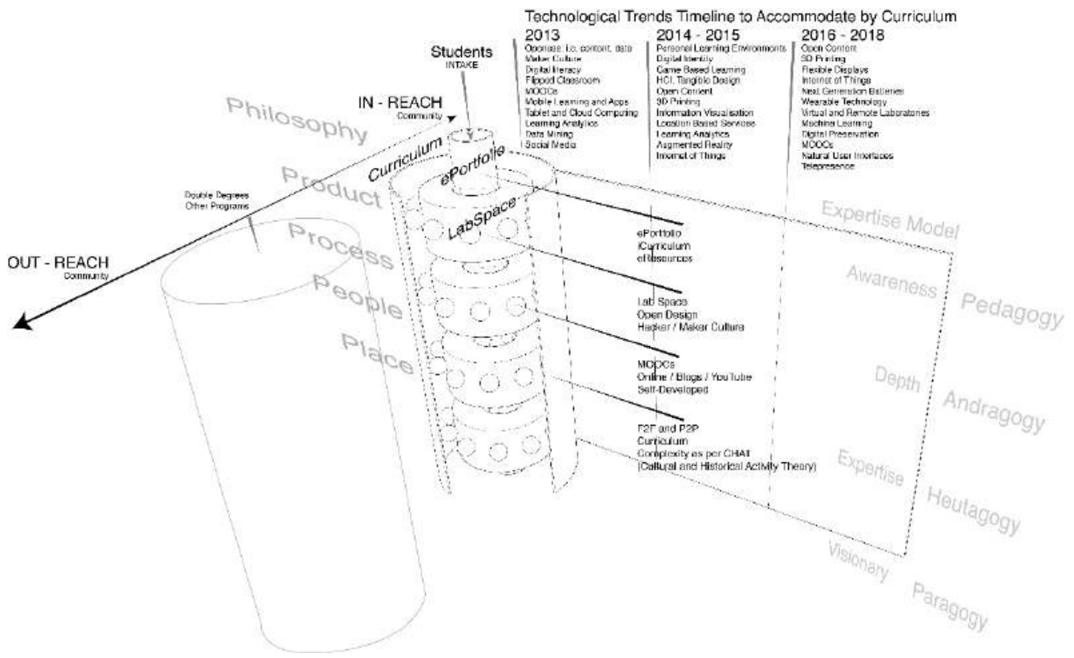


Figure 13: New design curriculum within space-time paradigm. Reprinted from Author, 27 October 2014, Industrial Design Curriculum 2016: New Vision and Imperative, Unpublished document.

By contrast, industrial design students' work was called sophisticated and is still in use (Figure 14). As per Black and Rankine (2013), weekly ePortfolio work was intended to "reinforce the different aspects of design process, emphasising the importance of visual and structural planning alongside textual descriptions". They collaborated on a range of design projects to "demonstrate their research and development process through submission of rich media evidence such as diagrams and videos as well as discussion and reflection". These students had higher demand use than other participants because of the need for designer and user control typical to this creative field. Admittedly, they initially had mixed responses to regular feedback on design process. Characteristically, students needed to modify any habits to work weekly with frequent constructive critique, design heuristics and some constraints due to ePortfolio software development (e.g. video format). Interestingly, several managed to personalise their ePortfolios by hacking the system (HTML5) before and after making them public to the internet. Participants who used ePortfolio the most were also those who performed best overall.

The four-year curriculum progressed alongside an evolution timeline, from *pedagogy* to *paragogy*, where a collaborative community reached inwards to the discipline and outwards to other degrees and industry. The first year focused on product making, introduction to design research, learning by playing, experimenting, tinkering, and general knowledge. The second year added process and methodology. The third year concentrated on people and behaviour, and the fourth year enveloped all and contextualised complexity as per place and time. Course attention expanded from assembly and manufacturing to HCD, design research and intermediation of human experience, new sociotechnical parameters as preeminent model of modern organisation, new maker culture, industry 4.0

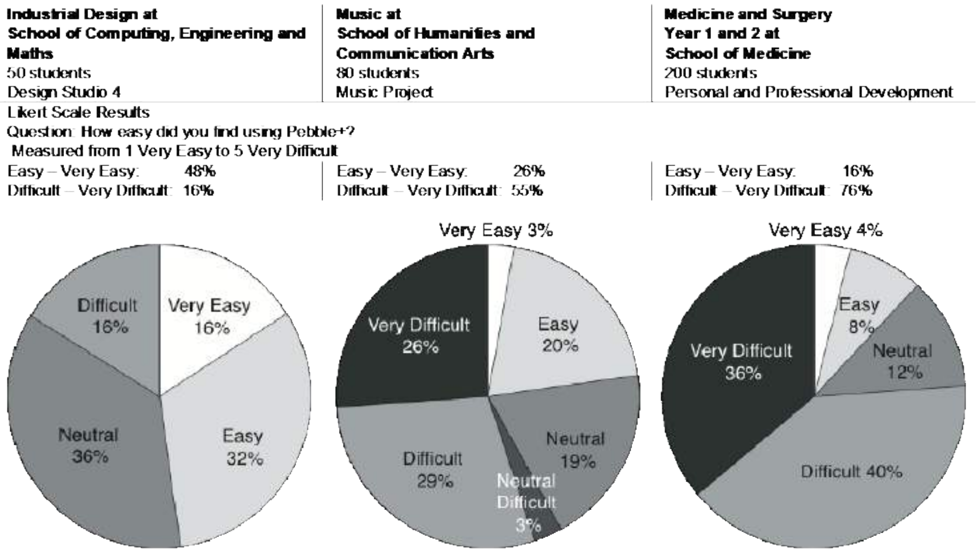
and open design (e.g. physical-digital artefacts, machines and systems built on shared information, free open-source software, hardware). As per several authors, including Gibson (2014); Maier and Fadel (2001); (2009); Norman (1999); (2013), this development catered for artefacts and systems potential actions to construct knowledge (*affordances)* beyond industrial age parameters. Also, action possibilities, which are normally latent in the environment until perceived by humans and animals, had by now evolved onto artefact to artefact *affordances* that sense each other and act without human intervention (e.g. algorithms, Google bots, Internet of Things).

Table 6: Course including ASA diagnosis, Lab Space, International Design Studio, Design Factory

	Industrial Design Curriculum							LabSpace	
								P2P & MakerHub	ePortfolio & Connected
(x) Unit Level		Core	Alternate					Industry projects convert to unit credit or industrial Experience requirement	
							Diagnosis		
			Major 1	SubMajor 1	Major 2	SubMajor 2			YouTube, MOOCs and other digital tools for self-learning drawing, drafting, materials, technology, etc.
	Design Research Methods	Design Studio Stream	Graphics & Visualization	Human Interaction	Des. Management & Entrepreneurship	Responsible Design & Sustainability	STEM foundation		
1 A	Intro to ID Methods (1)	DS1: Patterns & Products (1)	G1: 2D/3D ID Communication (1)				Design Science (1)	P2P Math and literacy (e.g. PASS, MESH)	
1 S		DS2: Form & Production (2)	G2: 3D Engineering Specs & Vis (2)	Programming Fundamentals (1)		Sustainable Design: Materials & Technology (1)	Math for ID (1)	Events and Competition (int-extern), Low-level MakerHub projects	Managing material information and tools: Granta Connexions
							Diagnosis		Diagnosis
2 A		DS3: Design Process & Function (3)	G3: Visual Simulation (2)	HCI (3)	DM1: Product Process (2)			Mid-level MakerHub projects: Social Impact. Industry competition	MOOCs: - Urich - Norman - Etc.
	One Major / Sub-Major Alternate or Elective								Diagnosis
2 S		DS4: Innovation through CDIO (3)	G4: Kinetic Narratives (3)	Tangible Interaction Design (3)	DM2: Manufacturing & Supply Chain (2)	Sustainable Design: Product, System, Services (2)		High level MakerHub Project: Social impact, TID, HCI, machine learning, robots, etc. Industry and Design competition	CDIO. Gaming and experience. Service and system design
	Two Major / Sub-Major Alternate or Elective / Industrial Experience								Diagnosis
3 A		DS5: Symbol & Meaning Making (4)	G5(4): Creative Computing	300976(2) Tech for Mob Apps	DM3(3): Org Skills for Designers				Critical making. Collective Networked thinking
	Two Major / Sub-Major Alternate or Elective / Industrial Experience								Diagnosis
3 S	Contextual Inquiry (4)	DS6: Ambient, Place & Behavior (4)			DM4: Strategy, Lean Startup & Entrepreneurship (4)			Design Factory: Design and industry research and innovation teamwork for social impact and new knowledge	Critical research and design. International Design Studio
	Two Major / Sub-Major Alternate or Elective / Industrial Experience								Diagnosis
4 A 4 S	Honours			Coursework					
							Diagnosis		Diagnosis

Note. Reprinted from Author, 27 October 2014, *Industrial Design Curriculum 2016: New Vision and Imperative*, Unpublished internal document.

Table 7: Pebble+ ePortfolio project Likert scale for three schools as per Black and Rankine (2013)



Industrial Design at School of Computing, Engineering and Maths 50 students Design Studio 4	Music at School of Humanities and Communication Arts 80 students Music Project	Medicine and Surgery Year 1 and 2 at School of Medicine 200 students Personal and Professional Development
Likert Scale Results Question: How easy did you find using Pebble+? Measured from 1 Very Easy to 5 Very Difficult		
Easy – Very Easy: 48% Difficult – Very Difficult: 16%	Easy – Very Easy: 26% Difficult – Very Difficult: 55%	Easy – Very Easy: 16% Difficult – Very Difficult: 76%

Note. Reprinted from Black, Elizabeth, & Rankine, Leanne. (2013). *Pilot Evaluation Report - PebblePad, Part 1*. Retrieved from Internal document (previously available in university website)

Figure 14: Constructivist and constructionist industrial design ePortfolio use. Reprinted from Author, 27 October 2014, Industrial Design Curriculum 2016: New Vision and Imperative, Unpublished internal document.

Bloom's Taxonomy was a bridge among disciplines (Anderson et al., 2001) but offered limited freedom to redefine design education. So, 12 unique course learning outcomes (CLOs) were developed afresh for the program. These shifted from the *hard-centre* and *abandoned-centre* models to a *liquid-centre* model, focused on both, empowering participants as agents of change and innovation based on creative intelligence parameters. CLOs started with *Exploring* and *Discovering* via research and knowledge mining before Bloom's stage of *Remember*. Design does not start with remembering, but inquiring what problem to disentangle. *Framing, Evaluating, Applying* and *Working* promoted framing and solving new knowledge landscapes through serious play (e.g. metaphor, 3D probing, scenario building), game theory (e.g. strategic decision-making), critical design and making (J. Roos & Victor, 1998, 1999; 2004). These activities connected the physical-digital gap with associative exploration pivoting between relations, concepts, prototyping, testing and scaling solutions to final artefact or service. Bloom's stage *Create* was diversified into 6 as *Producing, Delivering* and *Envisioning* artefacts that mark future trends, *Innovating* behaviours, products and services, *Creating* meaningful and effective sustainable solutions, and *Leading* by transcending affirmative design and social reproduction (Table 8).

Skills were grouped into competency envelopes. Per benchmarks (e.g. d.School, RISD, TU Eindhoven), they assisted in constructing design intelligence spaces that transcended disciplinary boundaries. *Being in space* completed the last century's definition of *being in time* for artefacts, disciplines and users. It acknowledged that thinking, doing and making happen in networked and hybrid human *spaces of coexistence*. This is the common ground among *runaway objects* that *instantiate* successful design and learning through interaction (Heidegger, 1962; Latour, 2009; Sloterdijk, 2011). Four envelopes containing skills for Making, Interaction, Visualisation, Strategy and Decision Making (Figure 15) fitted the new curriculum through user experience and new forms of manufacturing as knowledge-based innovation (biological, electrical, interactive, mechanical) amid users, users and artefacts, and between artefacts.

Starting with Dreyfus' cognitive acquisition model (Dreyfus & Dreyfus, 1980), the new course units built students' initial aptitudes up to ability dealing with novel design learning narratives (Product-Production, Process-Method, People-Participation, Place-Time-Practice). Students started as *Naïve* participants in first year. They became aware and empowered learners who increased their ability (e.g. gained depth, competency and proficiency) from *Novice* to *Advanced Beginners*. Several trials indicated they did learn by self-diagnosis (e.g. ePortfolio). *Expertise, Mastery* and *Visionary* stages were the result of transformative learning and ownership (e.g. practical wisdom, designing, making) capable of generating new knowledge, artefacts, experiences, and ecosystems (Table 9). Four new specialisation tracks were proposed for fourth year Honours program in the course. These dealt with industrial design's physical-digital challenges set as pathways for new mindset, theories and ways of designing that help transitioning into new ecosystems, lifestyles and society infrastructures: Human Environments, Responsible Design, Human-Centred Design, and Technology Development. Based on these same four design research concentrations, these pathways were discussed for further double degrees and postgraduate courses (Masters, PhD) to be considered in a next curriculum development.

Table 8: Industrial design course learning outcomes aligning with Creative Intelligence.

Bloom Anderson, Krathwohl 2001	ID Course Learning Outcomes Novoa 2011 - 2013	Descriptor	Creative Intelligences Nussbaum 2011
	1. Explore and discover market and user demands through design based research and contextual inquiry	Design based research	1. Knowledge Mining
Remember			
	2. Frame novel problems defined by environment, people and systems	Framing and defining problems	2. Framing
Understand			
	3. Evaluate complexity through interaction between products, processes, people and places	Evaluating complexity	3. Playing
Apply			4. Making
	4. Apply knowledge and skills to problem solving in a variety of fields deriving from traditional industrial design literacy to modern circumstances of human behavior, experience and interaction	Problem solving	
Analyze			5. Pivoting / Scaling
	5. Work responsibly and collaboratively according to values and principles dictated by professional code, culture and society	Teamwork and values	
Evaluate			
	6. Contribute to the community and business by demonstrating management and entrepreneurial qualities	Entrepreneurship and management	
Create			
	7. Produce functional and efficient market ready products using tangible and intangible materials according to needs and manufacturing constraints	Producing products	
	8. Deliver systemic solutions to produce designs that fit, adapt and improve human condition and sustainability	Systemic process	
	9. Envision future trends by managing ambiguity through critical thinking, logic, scientific reasoning and foresight.	Scientific thinking and foresight	
	10. Innovate on behaviors and products from basic research to well defined incremental, breakthrough and disruptive transformation	Transformation	
	11. Create new meaningful and sustainable ideas, structures and systems transcending typical innovation	Creativity and invention	
	12. Lead by example as agents of change to benefit environment, people and systems in our technology driven society.	Lead change	

Note. Data for CLOs from (Author, 2011 – 2013), for *Bloom Taxonomy* from Anderson et al. (2001) and for *Creative Intelligence* by Nussbaum (2013).

Contrary to earlier academics' fears, the new curriculum also attracted support and endorsement from school, university and outside community (academic, industry). Positive results showed along exemplar trials and when larger curriculum change occurred. This was a University-funded course change (over AUD 1.5 million) that evidenced prompt positive outcomes. It is worth noting that the industrial design ePortfolio project led to it being categorised as university exemplar in the area. Additionally, student retention improved, together with Student Feedback on Units (above school and university means for trial units), alongside the implementation of a collaborative and computing learning lab, design workshop, 3D printing lab (24 prototype machines from low to high fidelity and materials), MakerSpace and initial TechShop, software licenses that facilitated informed knowledge (e.g. material intelligence Granta CES Edupack), HCI and UX implementation with open source software support (e.g. Arduino, C++, Processing, Unity), and traditional tools and machinery. Renewed students' self-esteem was evidenced with participation in national competitions. First, second and commendation awards had no course precedent in events conventionally dominated by other universities (Cormack, 2013 - 2015). The

MakerHub concept benefited *work-integrated learning* that included Aalto Design Factory model-like projects.

Industry partners wanting to transform from traditional manufacturing to knowledge-based and design-driven innovation were attracted by this culture change towards the creative industries. Public acknowledgements were encouraging. As with a citation by The Creative Industries Innovation Centre, UTS Innovation and Creative Intelligence (Andersen et al., 2015) in relation to assisting Infasecure, a leading company in child safety and car restraint devices, to strategise design-driven innovation. An academics and students team led by Professor Mark Armstrong (Monash University) and this author assisted the company to deliver business growth, their first R&D industrial design department, and full employment for the participating students. Students' projects specifically aimed to improve children car safety and diminish driver distraction by introducing physical-digital industrial and HCI design intelligence. Sensors in seats and buckles detected child behaviour and symptoms to communicate with parents through colour, sound and wireless communication (Figure 16).

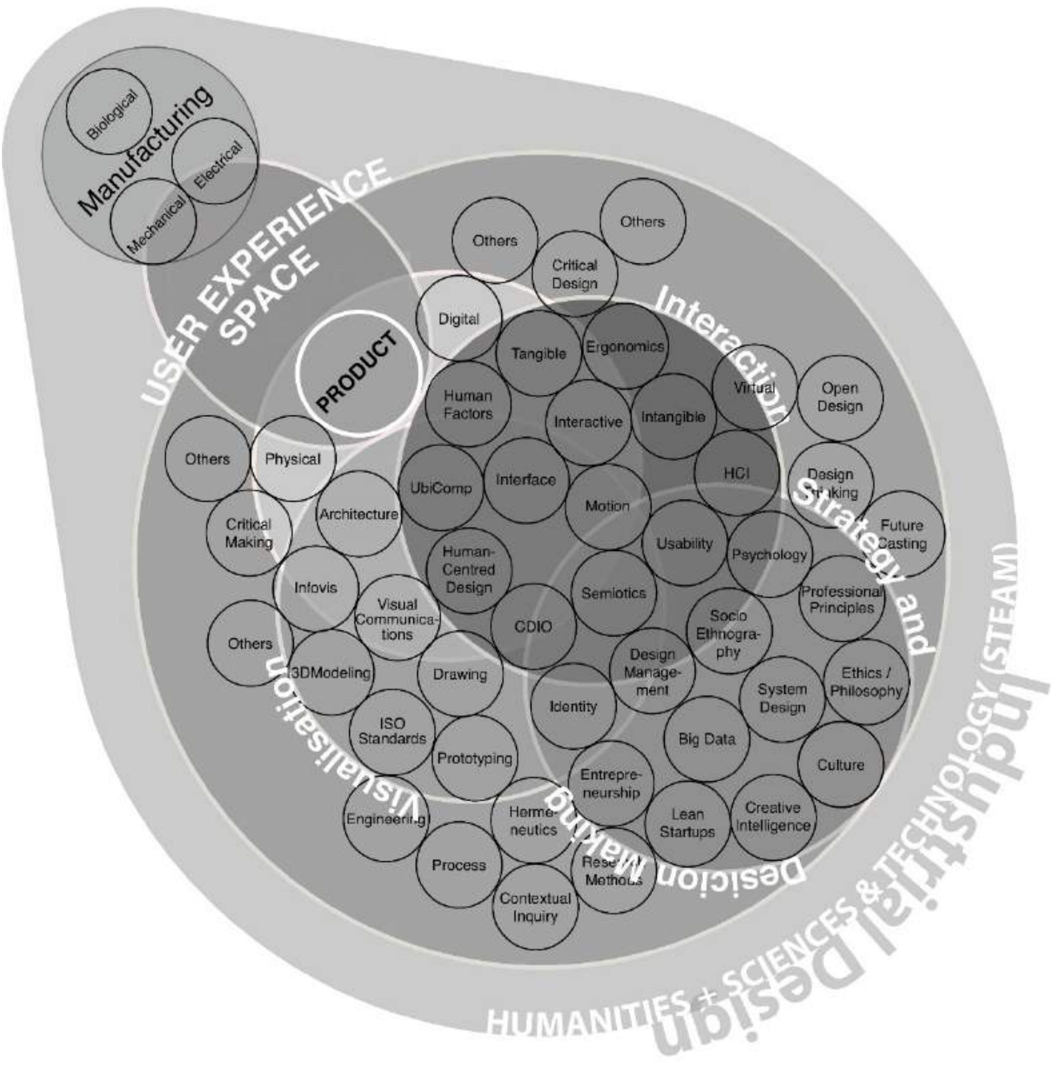


Figure 15: Competencies envelopes and spaces of coexistence. Reprinted from Author, 27 October 2014, Industrial Design Curriculum 2016: New Vision and Imperative, Unpublished internal document.

Table 9: Competencies and intelligence mapping

		Year (Autumn, Spring)	Evolutionary Focus: 5 P's (Novoa 2012)	Pedagogy	Mode	Skill Acquisition (Dreyfus & Dreyfus 1986, 2001, 2008)	Competency Centered Learning (TU/e 200??)	Literacy	Linguistics	Narrative	Design	Creativity	Organizational Management	Entrepreneurship
DOUBLE DEGREE			Philosophy			Ability		Creative and Design Intelligence						
			Diagnosis			Naive (Aptitude)								
	BACHELOR	1A	Product	Pedagogy	Transmission	Novice	Awareness	Foundation	Form Patterns (Morphology)	Linear Literal Denotative Analytical	Empathy Operational	Preparation	Functional	Discovery Experiencing
		1S	Product Process			Advanced Beginner						Incubation	Balanced Matrix	Concept Development
			Diagnosis											
		2A	Process	Andragogy	Transaction	Competent	Depth	Immersion	Sequences Structure (Syntax)	Procedural Methodical Interactive	Functional Symbolic			
		2S	Process People									Insight	Project Matrix	Resourcing
			Diagnosis											
		3A	People	Heutagogy	Transformation	Proficient						Evaluation		Actualization
		3S	People Places	Paragogy		Expert	Expertise	Integration Consolidation	Connections Meanings (Semantics)	Systemic Modeling Experiential	Contextual Cultural Collective Networked	Elaboration Disruption Originality	Venture Autonomous Startups	Harvesting
			Diagnosis											
		4A	Places			Mastery								
			Diagnosis											
		4S	Philosophy Product Process People Places		Generation	Practical Wisdom	Visionary	Fluency		Multidirectional Multimodal Figurative Connotative Synthetic Distributed				
			Diagnosis											
		5A 5S	DOUBLE DEGREE											
	MASTERS	6A	Philosophy Product Process People Places	Heutagogy Paragogy	Transformation / Generation	Expert	Expertise	Integration	Cultural Context Significance	Multidirectional Multimodal Figurative Connotative Synthetic Distributed	Contextual Cultural Collective Networked	Preparation Incubation	Venture Autonomous Startups	Resourcing
		6S				Mastery		Consolidation				Insight Evaluation		Actualization
		7A				Practical Wisdom	Visionary							
		7S						Fluency				Elaboration Disruption Originality		Harvesting

Note. Reprinted from Author, 27 October 2014, *Industrial Design Curriculum 2016: New Vision and Imperative*, Unpublished internal document.

Discussion

This article has described a three-year research project towards a new industrial design program launched in 2016. A new curriculum needed to consider cultural and historical constraints and potential, while capitalising on designers' and learners' adaptable and elastic minds. It also had to reconnect new forms of education and professional practice with its discipline heritage. *Redesigning* came to place with the realisation that successful design education should not only be about showing how to create physical objects for mass production in an input-output economy. In this new 21st century era, education should go beyond, into learning critically about a society characterised by highly interconnected sociotechnical and organisational networks within a creative and knowledge-based economy.

This repositioning of education allowed a new perspective from which to answer queries about whether an industrial design curriculum was capable of enabling a transformative design-driven innovation culture. This was especially pertinent when a transmission teaching model was the starting point and participants seemed in disadvantage comparing with international benchmarks. Findings showed successful local design learning was possible if the focus was changed to:

- Outcomes accomplished by stakeholders (users, learners, institutions, designers and academics) *instantiation.*
- Redefining design artefacts as epistemic instruments in the form of digital-physical platforms and projects that seek to address matters-of-concern, human activities and ecosystems
- Users' experience based on activity mediated by artefacts, their relationships and contradictions.
- Collaborative communities that emerge by co-creating values as *knots* in a grid of interactions and *runaway objects*.

Figure 16: Children car safety design-driven innovation through physical-digital industrial and HCI design intelligence. Reprinted from Mubin, O., Novoa, M., Ferguson, J., & Taylor, J. (2014), Leveraging the design of child restraint systems to reduce driver distraction, In

Proceedings of the 32nd annual ACM Conference on Human factors in Computing Systems (pp. 1771-1776): ACM.

Fittingly, the new program assisted students' cultural-historical development along the lines of a proposed industrial design history evolution (Product-Production, Process-Method, People-Participation, Place-Time-Practice). A constructivist and constructionist strategy were implemented to transition towards and align with international benchmarks that were based on empathic, exploratory and experimental *liquid-centre* learning models welcoming of other disciplines and users' *real particulars.* Significantly, from the first year, the curriculum was inverted to learn through and by *applied research* and *critical making*. Similarly, incorporation with outside user and industry communities was set to progress from industry coaching to final year Design Factory-like projects with a *work integrated learning* approach. Initial uncertainty was overcome by collaborative construction of knowledge that transformed participants from technology consumers to active cultural producers and mediators for social benefit. This opened the course to envisioning future human and industrial digital-physical iterations, space and time narratives, cyber-culture, 4.0 industrial revolution's automation, generative design and artificial intelligence.

Research results also helped the proposal that digitalisation could enhance, but not replace, many physical heuristic project-based forms of learning. A new curriculum had to address digital benefits and constraints. Used properly, digitality would assist learning, high-level thinking and reasoning to convert design into cultural, aesthetic and form intelligence. As a case in point, students intending to undertake fourth year Honours appreciated the ePortfolio process and methodology instilled in them. Similarly, those transferring to their teaching degree said ePortfolio was valuable and they would intend using it when teaching professionally. Furthermore, contributions from students indicated industrial design education should expand into digital materiality since 21st century knowledge flows are accelerating the discipline into the notion of living in a digitalised culture that blurs the physical and digital divide. Millennials and GenZ participants (students) did not make a big distinction between this divide when compared to Generation X and Baby Boomers (academics and other staff).

Remarkably, digital materiality borrows definitions, principles and properties from physical materiality to justify its existence and integrate design process (Leonardi, 2010; Negroponte, 1996; S. Pink, Ardèvol, & Lanzeni, 2016). This presents a new challenge for design and its education that now compete against contenders crossing over from other knowledge-based fields. Adversaries come from markets with the force of co-makers, open source technology communities, hackers, crowd-sourced ideas, subversive innovation, crypto-currencies, and new nature. People are considered products and platforms while patents are old-fashioned and design stars are no longer worshipped (Ardern & Jain, 2015; Jain, 2013, 2015).

A *constructivist*, *constructionist* and *critical design* curriculum offers a transformation pathway to design education still embedded within conservative institutional legacies. It greatly depends on customised and staged change, continuity of leadership, vision, and keeping true to new design artefact values. Similar to any design artefact, course success will be proven at the point of everyday *instantiation* by interaction amid users, users and artefacts, and between artefacts. Design learning is no longer about *affirmative design*.

Instead, it needs to assist academic, industrial and social change through design research and innovation-driven practice within physical-digital coexisting *spaces of being*.

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Review

Design as an Attitude

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Design writer and critic Alice Rawsthorn's latest book '*Design as an Attitude'* is a collection of her *By Design* columns written for Frieze magazine from 2014 to 2017. Composed of twelve chapters, each chapter tackles an area of design she argues that is transforming and impacting the world today. The *Prologue* defines what the author means by "attitudinal design". Opening with László Moholy-Nagy's famous quote from his book Vision in Motion "Designing is not a profession but an attitude", Rawsthorn writes a touching tribute to Moholy-Nagy. She attempts to demonstrate how she draws inspiration from his ideas in the argument for attitudinal design through the projects she discusses; projects that demonstrate resourcefulness and inventiveness to social, political and economic challenges of our time.

The use of the term "attitudinal design" feels like a movement from the 1990s – a term you would expect Thomas Frank to critique. And while the ideas are drawn from Vision in Motion (published in 1947), what is striking is that Moholy-Nagy's ideas remain relevant today, where he saw "design as an attitude" as the "potential to become a more powerful force in society by acting as an efficient and ingenious agent of change, free from commercial constraints" (p.9).

The chapters are short and easy to read, each possessing a short reference list of cited work, and Rawsthorn presents design in an accessible form to the audience. The book is good for anyone interested in understanding design and its role in everyday life. The main critique is that the chapters end in an abrupt manner, however, they open up debates and opportunities for critiques. Recurring throughout is a focus on technological change and digital tools. Rawsthorn invests heavily in the idea that these will move design away from specialisation, and in opening up avenues for diversifying the discipline. Another recurring focus is an attempt to shift perceptions on design as merely a styling device, and demonstrating the relevance of design in addressing political, social and economic issues.

In a similar way to how she begins the prologue through an engaging telling of Moholy-Nagy's journey prior to publishing Vision in Motion posthumously, she begins Chapter 1, *What is Attitudinal Design*, with the story of Willem Sandberg, who she describes as the personification of design as an attitude. This chapter continues on from the prologue, drawing on examples from history who have used design as a defence for human rights.

Chapter 2 signals a shift, dealing with what is considered an exhausted topic: the difference between design and art. The author does well in placing this here as she sets the stage of sorts regarding what she defines as 'design' and 'art' and when these lines blur. The aim of the chapter is to reiterate that design is not merely a styling tool. Interestingly, the chapter opens with a quote from Jean Prouvé "if people understand there's no need to explain. If they don't, there's no use explaining" (p.29). Reading this, we wonder, is this chapter's inclusion necessary? As the book targets a general audience, its inclusion is logical. Rawsthorn recounts the historical rift between the terms, and how artists and writers contributed to defining design as aesthetics. She makes relations on how artists and art institutions have a growing interest in design through "exploring the impact of digital technology on the ways we relate to the world" (p.34), using the work of artists like Ed Atkins, Helen Marten, Yuri Pattison and specific exhibitions to demonstrate her point. However, that these ideas are drawing from design is hardly recognised within the art world but rather become practices absorbed by art. This chapter sets the tone for Rawsthorn's call emerging throughout *Design as an Attitude* – of abolishing the disciplinary boundaries (the specialism Moholy-Nagy warns against) in favour of a more collaborative and generalist approach to design.

Chapter 3, *The Craft Revival*, begins with the story of William Morris at Crystal Palace. Disappointingly, the majority of the historical examples draw from Western design history and feature the same actors we come to expect with books on design. The historical context on crafts, while interesting, is at the expense of a more pertinent conversation: the marginalisation of crafts as it was perceived as 'feminine.' Moreover, what Rawsthorn describes as the "[e]qually problematic … dismissal of the craft traditions of developing countries" (p. 43) is a mere paragraph that glazes over the debate of 'good design'; a term equated with the West, whereas everyone else (i.e. the so called non-West) does 'crafts'. Indeed, her discussion on the use of craft symbolism and techniques amongst Dutch designers feels like a 'craft revival' but does crafts only become 'design' when the Dutch produce it, despite crafts and design being more intertwined in other parts of the world? What this chapter does well is tie crafts to contemporary technological advances; who is a maker? What is now considered crafts? These are important questions to debate.

Rawsthorn's understanding of design is particularly vivid in Chapter 4, *The Descent of Objects*, when she discusses the Darwinian evolution of objects. She enables the reader to understand the importance of objects in our lives. While this chapter makes for a compelling argument, as a designer, I cannot help but feel that its weakness is in discussing the translation of these objects from the physical to the digital world. For example:

> Our phones and computers have become progressively smaller, lighter, and faster … [and] are able to fulfill the functions of hundreds of different products: from printed books, newspapers, magazines, diaries, and maps, to telephone kiosks, cameras, calculators, watches, Rolodexes, sound systems, television sets … (pp.52-53).

Computers and phones have rendered the use of different products much easier, but if we take the example of how some products and services translate from the physical into the digital, the transition is not always seamless. Why are we not analysing how digital equivalents have migrated into the digital form rather than praising their physical obsolescence?

Rawsthorn covers all aspects of design, including graphic design. Chapter 5, *Back to the Future*, begins with a history of the hamburger icon – the drop-down menu now ubiquitous on websites. The author does a good job of relating the appearance of the icons on the screen to the objects we engage with daily, an aesthetic that she describes as “steeped in nostalgia” (p.63). She draws on Apple as an example and their inability to fully embrace flat design as their competitors have, a style that she is equally critical of for being nostalgic. The chapter ends with an important reminder on the future of designing user interfaces: user interfaces are not “encumbered by formal constraints. There is no legislative pressure to use specified operating symbols, or an industry-wide agreement that compels companies to do so” (p.65). Rawsthorn presents designers an opportunity for future development: the ability to develop a new aesthetic unencumbered by nostalgia.

Chapter six poses the question *Is design still a (cis) man’s world?* Important arguments from chapter three are picked up here. Once again, Rawsthorn engages the reader through historical context. She reminds the reader of how female designers who have made a name for themselves in the past was largely due to wealth, social connections, or through marriage (to a famous male practitioner). The chapter is a good primer on issues faced by female designers within a man’s [design] world and the progress they have made – progress that Rawsthorn feels will be empowering to women in the future due to advances in science and technology that will call for new disciplines, enabling women to operate independently “free from the constraints of old boys network” (p.74).

Chapter 7, *Design’s Color Problem*, starts off with a discussion on the absence of black designers from design history. The “things are changing” argument is repeated from chapter six, but it is difficult to see how the process of including a few new designers and more exhibitions are addressing this absence. Instead, she frames it as a diversity issue. But diversity is ticking a box, and Rawsthorn fails to acknowledge that inequality is both systematic and structural. The chapter then moves on to discuss several projects – emphasising ‘digital design’ – from Africa, Latin America and South Asia. These projects, she argues, could inspire designers from the Global South with “more ingenious and ambitious ideas while encouraging their peers in other countries to be more perceptive and generous about fostering greater diversity and inclusivity within their own design communities” (p. 84). It is difficult to see how exactly. Despite her argument that the influence of European modernism on design culture from the twentieth century – a style that favoured standardisation over diversity – is disappearing thanks to the ability to customise outcomes due to technological advances, the fact is modernism remains highly influential because it represents the standard of ‘good design’ and is emulated all over the world. Additionally, museums and galleries continue to produce exhibitions on its leading figures, and its principles remain the main readings of design courses across institutions.

Chapter 8, *The Fun of the Fair*, is one of the strongest chapters. It presents a well-argued critique of the Salone del Mobile’s continued relevance in design culture. While successfully launching the careers of many designers, furniture’s cultural impact has diminished since the Salone launched in the 1960s. Rawsthorn argues that students are less interested in becoming “mini-Starcks” and more interested in “making meaningful contributions to ecological catastrophes, or to redefining design’s interpretation of gender identity” (p.93). While questioning the Salone itself, Rawsthorn remains optimistic as smaller cultural events spring up. Here is where a relation to arguments in the previous chapter could have been strengthened: how does the appearance of cultural events in other places contribute to the development of more progressive design cultures outside of Western design centres?

Chapter nine discusses customisation as technology and demand offers consumers more choice. The argument in this chapter is not entirely convincing however as the examples she draws on are at times confusing (as with the case of Rachel Dolezal). The chapter raises questions that it leaves unanswered: does customisation prevent waste? What other options do we have versus mass availability? Does customisation give consumers the illusion of being unique and authentic? And is it possible to talk about the waste caused by industrialisation but not argue against consumerism? The examples used revolve around gender and Rawsthorn's reading of these, rather than designers being informed enough to consider how gendering objects has been used as a marketing tactic historically. This is an opportunity to discuss how design education helps inform designers of the ideologies they embed within their design work, but there is little to no mention of design education across the book, or how these changes are affecting the agendas of large companies that can influence the conversation on design and production. Throughout the book, she attempts to argue how a new generation of designers use digital tools to pursue their own goals by operating independently – "liberating" design from its role as a service-provider. But these conversations remain on the fringes – how are these projects impacting design education and influencing larger companies? The power large companies possess is mentioned in Chapter 10, *Out of Control*, a chapter she ends with an interesting discussion on the 3D printed gun and the unintended consequences of design work – or the design work whose consequences designers fail to fully consider. There is an interesting debate to be had that in relation to design education here.

Chapter 11, *Design and Desire*, discusses new found attention on touch and the increasing importance of other sensual qualities such as scent. The long focus on worldview throughout history has been discussed extensively in other disciplines (vision at the expense of other senses). It would be interesting if drawing on examples of design projects from the Global South could demonstrate how other senses have been emphasised. The chapter attempts to argue that other senses and qualities will become determinants in design's desirability, leading to a more sophisticated understanding of design and less rubbish. The diminishing power of design as a styling tool argument is referred to again: "However much you enjoy the phone's styling, the pleasure you take in its appearance will not last long if it is infuriatingly difficult to operate" (p.128), yet we are far from this. Desirability remains one of the main reasons why we choose our devices (iPhone X for example), and why people continue to force themselves to use badly designed objects.

Chapter 12, *When the Worst Comes to the Worst,* starts off with the story of Dutch architect Jan Willem Petersen analysing the flaws of the Task Force Urzugan project and how rigorously he prepared and immersed himself in the work. Rawsthorn highlights the importance of research but despite writing how "such endeavors are admirably intentioned, and many of the gutsiest, most dynamic designers of our time are working on them" (p. 133), she cautions that they should be "planned and executed to the highest possible standards, given the political sensitivity of working in volatile, often perilous situations where the consequences of failure can be calamitous" (p.133). While it is difficult to disagree with this statement, the chapter does not critique the NGOisation of design and the dangers this approach poses, a topic that several scholars have written about. Instead, Rawsthorn argues that despite an increase in social design projects, they "have had little impact on the popular stereotype of design as a commercial styling tool" (p.133). Further in, she discusses how local projects have proved more successful and this leaves the reader wondering why the chapter begins with a discussion on global non-profits rather than featuring local projects where designers are familiar with the context. The last few examples draw on designers 'helping' with the refugee crisis, another topic that has been critiqued in academia. She does not discuss the lack of awareness amongst most designers working in these situations and how the proposed solutions generally maintain the status quo. To practice attitudinal design is to become an agent of change, to be resourceful, collaborative and inventive, but these examples fail to demonstrate these qualities.

Politically, the statements remain similar to any other design book: light. Rawsthorn's accessible writing has the opportunity to provoke, but she does this through safe topics – hence the emphasis on technology and gender identity. The book attempts to display a sense of 'diversity' or 'inclusion', but this does not question – radically enough if we are to consider the title of the book – the state of how things are. Despite appearing like a manifesto, Rawsthorn does not provide any possibilities for action. If this was a manifesto, then it would have a stronger call to action. As she writes "[n]ot that every designer will turn attitudinal; nor should they" (p.11). It is important to remember that the original form of each chapter as columns for Frieze targeted a general arts readership, and this explains the examples being familiar to anyone in design and not as thought-provoking as it could be.

Discussions on the role of design as an agent of change have been debated for decades within design education, but only recently has the design industry taken an interest in the matter, and yet they remain within the confines of traditional definitions of design, hardly questioning design's role as a mere service-provider. Despite its safe political statements, *Design as an Attitude* is an excellent addition to anyone interested in design or those who never paid much attention to it. It is accessible and informative, with enough historical references to provide background context.

The accessible writing of *Design as an Attitude* and the range of contemporary design issues it covers from gender, ethics, politics, race, disciplinary boundaries, and technology amongst others, may prove useful for design educators teaching at the undergraduate level, and as an introductory text to design at the secondary school level.

What *Design as an Attitude* does well is bring up how much of design is hidden, anonymous labour, generally female labour, and how these contributed to the success of the lone, celebrity designer. Rawsthorn does not only remind us but makes an effort to name this labour throughout the chapters and through the glossary of designers and design projects at the end.

The design of the book is worth mentioning because it is thoughtful. It is typeset in Genath throughout, displaying excellent attention to the power of different sizes and weights of one typeface. Whereas many books take full advantage of page 'real-estate', the decision to include large margins allows for comfortable marginalia, and a pleasant reading experience. For a book on attitudinal design, this is a conscious design decision, and can be viewed as a statement against publishers cramming in text to fit a certain number of pages to ensure cost efficiency.

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