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Table of Contents

Differences, similarities, themes

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With a new year and a new Volume (our 23rd) of the Journal, we once again provide a range of articles from different levels of education, different national educational contexts and different areas across Design, D&T and Technology Education. This issue includes contributions from India, Ireland, Turkey, the USA, Italy, New Zealand and the UK with focuses on mainstream schooling, higher education design, architecture, outreach work with underrepresented communities and individual child and adult innovators. But across this range of difference, the threads of interest and concern for learning and teaching appear. As editors, one of the pleasures of reading all contributions is seeing links between what seems at first to be disparate pieces and the insights, understandings and reinforcement that comes, for example, from three quite different articles that have in common a thread of insight into the impact that digital tools have on the way people learn and perform.

Much as we value the serendipitous nature of a journal with such a wide spread, we are also concerned to support deliberate curating of links. The Journal has a history of themed issues with guest editors and with this new volume we are introducing a slight twist to the approach that will mean that some issues will be completely mixed, while others will have both a guest edited theme section and a more open ‘all comers’ section. Issue 1 of Volume 23 is of the ‘all comers’ type. But Issues 2 and 3 will both include guest edited sections, drawing together articles developed from conference papers from the 2017 Engineering and Product Design Education Conference. We hope this approach will ensure that people submitting individual articles will be able to see these coming to publication as quickly as possible, while we also offer a space for articles that have a shared focal point. We welcome proposals for themed sections, and please make contact if this is of interest.

But now we turn to this Issue, which begins with current musings of Richard Kimbell, this time reflecting on how value is created. In *The limit of zeros* he ponders on ways in which wealth is expressed. He starts with a 6th Century mathematician and astronomer named Brahmagupta who explained the importance of zero when computing number. This is followed by a wry comment that current day hedge-funders make use of that by turning small sums into large ones. He points out that having a balance sheet with lots of zeros doesn’t allow one to express wealth as forcefully as owning a Fabergé egg, creating the Sistine Chapel or owning a 1962 Ferrari 250 GTO, all products of creativity and of the made world that express enduring value of material culture.

The research articles in this issue start with a fascinating study undertaken in India that explores differences between children and adults as innovators. In *A comparison of problems at the grassroots level in India identified by adults and children: Implications for Design and Technology Education* Sachin Datt and Sugra Chunawala (Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research, India) draw on a national database of innovation to analyse differences between innovations and innovators. The database itself is extremely interesting (http://nif.org.in/award-profile). Held by India's National Innovation Foundation it showcases grassroots innovations from problems self-identified by either adults (post 18 years old) or students (pre 18 years old) that have been given an award by the Foundation. Datt and Chunawala analysed 246 innovations awarded between 2012 and 2015, focusing on differences in problems identified by adults and school students and exploring what the reasons for the differences could be. They were keen to gain insight into implications for design and technology education, including what young people saw as authentic problems to tackle. Innovations were placed into one of 21 categories (for example agriculture, health, pest control, tree climbing) and then divided into adult or student innovators. Some categories featured both groups, some had only students or adults and these differences became a further focus of their attention. Analysis revealed more divergent ideas in the adult population, and differences in focus, for example adults focusing on agriculture, health and cooking, while students were concerned with 'prohibition' innovations –technological approaches to dealing with human behaviour such as bullying or people not stopping at zebra crossings. Findings are related back to literature on creativity and on novices and experts and the authors suggest that their findings are potentially contradictory to views that children are more creative than adults. Finally, the analysis opens up insights into what young design and technologists see as authentic and relevant challenges to be tackled, extremely valuable for all those engaged in education at school level.

The next three articles each explore links between design and technology education and the use of digital tools.

The first focuses on learners in the upper age group of mainstream schooling. In *Balancing Curriculum Intent with Expected Student Responses to Designerly Tasks*
Jeffrey Buckley (KTH Royal Institute of Technology, Sweden) and Niall Seery, (Athlone Institute of Technology, Ireland & KTH Royal Institute of Technology, Sweden) examine the effect of parametric and non-parametric modelling systems on designing. The research was undertaken in Ireland with learners studying a certified course in Design and Communication Graphics that has two overarching aims: developing creative and designerly competencies and developing technical expertise. The aim of the research was to see if, by controlling the CAD system the learners used (either parametric or non-parametric) there was an effect on the output of their designing and the learning outcomes achieved. Two equivalent groups were compared, both groups with the same design brief, but one group

using a parametric CAD system (SolidWorks) and the other a non-parametric system (CRE8). Findings indicated that, from the outset, differences were seen. This included the non-parametric group making more use of sketching and annotation while the parametric group used technical drafting and text, the non-parametric group's designs were more organic and showed more depth in their ideas. The authors draw attention to the extent to which the learners' mode of operating appeared to be controlled by the tools they were using and the ways that teachers can 'orchestrate' activities that manipulate how learners respond and what they learn. The split that appeared between creative and technical responses causes them to call for teachers to create a balance in the experiences provided.

In *The Use of Metaphors as a Parametric Design Teaching Model: A Case Study* Asli Agirbas (Fatih Sultan Mehmet Vakif University, Turkey) presents research conducted with undergraduate architecture students. The focus of the research was to explore the potential of metaphor as a stimulus for designing whilst teaching parametric architecture tools. After providing a range of historic metaphoric architecture created before the introduction of computer aided design, Agirbas moves to suggest that, with the advance CAD software based on non-Euclidean geometry, it is important for architecture students to learn how to use it. The research questions addressed were "How can effective teaching of parametric design tools be done in a limited period of time?" and "Is it possible to use metaphor in a methodological way within the system of parametric design education, which can guide the student in the design process?". Students were introduced to a range of software not previously used and to digital fabrication processes, alongside being introduced to the idea of using metaphor in designing and this was followed by students applying both in a design project. The impact of the approach was explored through studio observation and one to one discussions with the students in addition to an analysis of project outcomes. The research provided insights into how the students used metaphor in the development of their designs, into the versatile thinking that that learned as they combined the different aspects integrated into the project (coding, digital fabrication, material based thinking etc.) alongside more general learning, for example developments in time management. As the author points out, while the insights from the project of particular value in architecture education, they also hold value across design education more generally.

A further article that focuses on learning and digital tools is provided by Tilanka Chandrasekera (Oklahoma State University) and So-Yeon Yoon (Cornell University). In *Augmented Reality, Virtual Reality and their effect on learning style in the creative design process* they explore learner preferences when designing between Virtual reality and Augmented Reality interfaces. Following a detailed discussion of learning styles, creativity, motivation and acceptance, in relation to learning preferences, they present a study where the learning preferences of 30 design students were compared when using the two interactive environments. The study suggested that users perceived Augmented Reality to be easier to use, more useful and more likely to be used in future. They anticipated that kinaesthetic learners would prefer an Augmented Reality environment and found this to be so, but also found that visual learners also preferred this – something which surprised them. While theory makes connections between perceived ease of use and creativity, their study did not confirm this.

Taken together these three articles provide valuable insights into processes of designing as more and more digital tools are utilised- something of considerable importance for design and technology educators working with learners at any stage in education.

The final two articles are concerned with aspects of design and technology education (first architecture and second STEM) and its impact on future employment.

In their article *Reflecting on architecture curriculum through a survey on career switching* Shenghuan Zhao and Enrico De Angelis (Politecnico di Milano, Italy) and Dongqing Ma (Dalian, University of Technology, China) provide interesting insight into the ways in which chinses architecture graduates are switching careers away from architecture and report on their research to see how this relates to the architecture curriculum. They report on a large scale survey that identified the reasons why architects are shifting careers and then on an analysis of university architecture curricula pinpointing mismatches between current needs of the profession, mission statements by universities and the actual curricula that form the basis of the students' education. Based on this they identify the need for a shift in curricula that allow more time for integrating emerging technologies and developing self-learning skills while reducing time spent on art and human science courses. They suggest that there is an existing over pre-occupation with these courses in Chinese architecture education. It would be interesting to see the extent to which other architecture educators agree.

The final article, *Outreach programmes using the Triple Helix model to encourage interest in Science and Technology among underrepresented youth* by Sangeeta Karmokar, (Auckland University of Technology, NZ) and Aruna Shekar, (Massey University, NZ) provides a case study of an initiative that focused on raising awareness of entrepreneurship and STEM education amongst underrepresented groups, in the authors' New Zealand context this focused on Māori and Pasifika school students. The project adopted a triple helix model, bringing together business, government, universities, researchers and school students and their parents. The article provides some background the underrepresented groups generally and also in the context of New Zealand, with a particular focus on STEM. The research aimed to explore activities that would increase aspirations towards STEM in underrepresented young people. These aspirations were facilitated through a set of workshops that provided an approach that transformed a traditional classroom approach into a discovery zone focused on inquiry based problem solving. The approach involved both inspirational speakers and hands-on designing and making workshops that were based on engineering education, but that made connections to indigenous cultural and social values of the participants. The authors report on the positive reactions from the students and, based on the workshops, make suggestions of ways to engage students from underrepresented communities including collaborating with communities, encouraging drawing on values and traditions of the participant groups and projects with real world challenges, involving role models from their communities and drawing together stakeholders through a triple helix approach.

Finally, this issue concludes with reviews of two recent books that will be of great interest to any reader of the Journal.

First, we have a review, provided by Derek Jones, of *Art and Design Pedagogy in Higher Education: Knowledge, values and ambiguity in the creative curriculum* by Susan Orr and Alison Shreeve. Focused on Higher Education and with a background in the UK context, the book provides a wealth of insight into studio-based pedagogy, taking on the challenge of exploring what the authors themselves describe as the ambiguity, contradictions and paradoxes of practices of creative teaching and learning and what they refer to as the 'sticky' curriculum.

This is followed by a review provided by Jeffrey Buckley of the latest publication from Loughborough Design Press - a collection edited by Eddie Norman and Ken Baynes entitled *Design Epistemology and Curriculum Planning* that contains chapters by both editors as well as those by Stephanie Atkinson, Alison Hardy, Steve Keirl, Graham Newman, Tristram Shepard, David Spendlove and Xenia Danos.

Taken together, these two books provide much needed focus on pedagogy and curriculum and give a depth of opportunity for critical reflection on the practices of design education.

We hope you enjoy reading the articles and reviews in this issue and, as always, welcome comments.

The limit of zero

Richard Kimbell, Goldsmiths, University of London

Sometime around the year 600, an Indian mathematician and astronomer named Brahmagupta wrote (in Sanskrit) a theoretical treatise in which he first explained the importance of zero and the rules for computing with it. He has a lot to answer for. With £1 in the bank, a few strategically placed Brahmagupta zeros can transform it into a hundred, or a thousand, or a million, or a billion. What a boon it has been for hedge-funders, who just have to add all those zeroes to their bonuses … but more of that later.

There is no real limit to the wealth one can accumulate. But (unless you are very peculiar person) there is limited delight to be found in staring at a balance sheet, however many zeros it contains. So we are driven to find other ways of expressing our wealth and it seems that throughout history the last resort of wealth is artistry, design and craftsmanship. The Tzars of old Russia were good at it, as epitomised by the fabulous Faberge eggs of the late 19th C or Peter the Great's 18th century 'Amber Room' in St Petersburg with 55sq metres of exquisitely carved panels amounting to 6 tons of amber. Incidentally, the book 'The Amber Room' by Steve Berry is a fascinating account of its creation and its loss when it was all moved by the Russians to avoid capture by the advancing German army in the 2nd world war. Tantalisingly, it remains hidden/lost.

It seems that everyone with loads of zeros in the bank seeks the talents of artists / designers / craftsmen – and it has been the same throughout time. The Anglo Saxon nobles who had magnificent golden torcs made for them; the pharaohs who commissioned the pyramids; France's Sun King Louis XIV and the Versailles palace; the Catholic church with Michelangelo's Sistine chapel in Rome; the bishops of England with a whole string of fabulous cathedrals. The trend does not look like changing, Lloyds of London – the shipping insurance giant – commissioned Richard Rogers to create the Lloyds building at the heart of the city of London and of course the Trump pad in Manhattan, that (I am led to believe) used up the entire stock of gold leaf available in the USA.

I imagine that there are many motivations underlying this trend. The church hierarchy no doubt claimed to glorify God (whilst glorifying themselves in the process); for some I'm sure its seen as a better investment for their money than zeros in the bank; and for yet others it will be the need to make a big public 'statement'. But in any event, the translation of bank-balance zeros into objects in the material world, is an act of creating *enduring* value. A balance sheet may have some transient financial attraction, but a 1962 Ferrari 250 GTO is not just an object of rare beauty and awesome power – it is also the world's most expensive car ($35 million). It would certainly be a good investment, and it certainly makes a statement.

I am reliably informed that the latest breed of big-money earners – the hedge fund managers – are hard at it.

> The world's leading art collector is Steven Cohen, the head of SAC Capital …. After Cohen, many of the other major art buyers are other hedge funders, Russian gangsters, and Chinese billionaires. (Michael Wolff. *Why really rich men try to take over the art world,* Guardian on-line. 7th Oct 2013)

Interestingly this trend of converting money into beautifully crafted objects has wider application and occurs also in the intellectual world of ideas. It is evident in writing and manuscripts. The monks of Lindisfarne (who were not personally wealthy – but whose church definitely was) were not content merely to write their account of the Gospel, they celebrated it with the most richly ornamented ('illuminated') artwork. They devoted years of their lives to creating magnificent texts, and then bound them in fine leather encrusted with jewels and precious metals. Whilst the cover of the Lindisfarne Gospel did not escape the Vikings' plundering, the astonishing illuminated text did and can still be seen in the British Library. The Book of Kells provides another beautiful example. It is a masterpiece of calligraphy and illumination and is widely regarded as Ireland's finest national treasure. It too can still be seen, in this case in Trinity College Library in Dublin. To say that such pieces are priceless, is to say they are beyond the limits of zero.

In a very small way I have experienced the richness of such books myself. We have a set of books at home (inherited years ago from someone in the family) that includes a limited 1st edition of the Hans Anderson fairy tales. Beautifully bound in soft leather and with dozens of exquisite illustrations, when you flick through it, it makes you realise that there is more to reading a book than just the attraction of a good story. It is an aesthetic experience of visual delight, touch, smell and history. I get a different but similar jolt from reading back through some of my old text-books from school and university, though there the attraction is less about visual delight and more about repositioning myself through my frequent jottings-in-the-margin that say so much about my own personal history. And when I was using 2nd or 3rd hand text-books, the jottings are occasionally from previous owners, which adds more complexity and interest to my reading.

A bit belatedly perhaps, I promise I am coming to the point of this disjointed rambling. For it is with some sadness that I have noted the passing of the journal. Not of course the digital version that resides in cyber-space and that you are presumably reading at this moment, but the real physical one. The one to flick through, to make jottings in, to keep on the shelf, to feel and to smell. I completely understand the logic of the e-journal. It is obviously cheaper to produce, but moreover it is far easier to distribute to a wider audience, and –

once received by the reader – it is simpler to store and (importantly) easier to search and retrieve what you want. And D&TA did not print many as hard copy anyway. But all that logic does not stop me from regretting the loss of the hard-copy version. Whilst reason points to the functional efficiency of the e-form, the emotional / aesthetic power of the 'real' thing – as the monks of Lindisfarne knew - has a pull that goes well beyond such logic.

I was tempted to get carried away writing of the destruction of the 'real' journal as a parallel to the Viking destruction of the Lindisfarne library, but then I remembered that I too have been accused of a similar form of vandalism – by promoting (within project e-scape) the idea of web-portfolios rather than real paper ones. We spent years trying to find software drawing/modelling tools that learners could use with the same ease and simplicity as they might use a pencil. We know that with early design ideas, ease of expression (in whatever medium) is absolutely critical to learners being able to get their ideas out of their heads and into reality. We created a powerful digital toolbox for learners to create their web-portfolios and much of it worked brilliantly, but I was never really convinced that the software did justice to those critical first marks. When a half formed idea is struggling into reality, we never found a better medium than a pencil. As with the journal however it was the ease and efficiency with which we could enable learners to do other things that drove our decision-making.

Returning to my theme of the limit of zero, it is interesting to see that it is not just fabulous works of art, design and manufacture that now attract the hedge-funders, but also the designers' jottings and sketches. Leonardo's sketch-books, and all his preliminary works are avidly snapped up for huge sums. A preparatory drawing for his Adoration of the Magi - never finished - recently sold in New York for $8m. And a few years ago, the V&A mounted an exhibition - 'Savage Beauty' - of Alexander McQueen's drawings from his Central Saint Martins MA graduation portfolio. The brochure described how the drawings 'provide an important opportunity to understand how ideas were expressed at a stage prior to any cutting or tailoring using fabric on a mannequin'.

The creative world has a rhythm that has stayed pretty much the same over centuries and even millennia. Artists and designers turn ideas into fabulous objects, and – in turn – wealthy patrons (hedge-funders) turn their zero's into enduring value. Throughout this complex exchange, the concrete world of materials and tools intervenes, first to facilitate the design & development process and then to leave behind a permanent record of it. When archaeologists dig through the remnants of the city of London a thousand years from now, it will be this material world that they gradually uncover and seek to interpret. However hard they look, they will not find a hedge-fund, but they will find buildings and tools and clothes and (maybe) a 1962 Ferrari. Our culture is defined by what we create. This is enduring value.

A comparison of problems at the grassroots level in India identified by adults and children: Implications for Design and Technology Education

Sachin Datt and Sugra Chunawala, Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research, India

Abstract

The focus of Design and Technology (D&T) education (Wilson & Harris, 2004) has been on designing and making activities and in developing technological capabilities amongst students. Innovation is an important aspect of D&T that helps in creating new products and artefacts to overcome the limitations of existing ones. Problem solving and problem identification are inherent components of innovation and D&T education. This study aims to compare differences in problems identified by adults and children at the grassroots level in India. In particular, we ask what kind of differences are there in problems identified by adults and school students and what could be the reasons for the differences and its implications for design and technology education? The data of innovations was accessed from the website of the National Innovation Foundation (NIF), India. The innovators, both children and adults, had not received any design brief by an external agency and the range of problems identified by them were from diverse areas. We grouped the problem areas into a number of categories. Contrary to conventional wisdom and literature about children being more creative than adults, we found a greater diversity in the problems tackled by adults. More importantly there were qualitative differences in the kind of problems identified by adults and children. Interestingly a category of problems that children identified was related to human behaviour and students attempted to fix these behaviours through technology.

Key words

Innovation, Creativity, Problem identification, Design and Technology Education, Children, Adults

Motivation for the study

Innovation, has been recognized as the key driver of economic growth (Gallagher, 2012; Rosenberg, 2004) and there is a wealth of research about innovation and how it can be nurtured in individuals and organizations. However, an important question to ask is, what avenues are available for the citizens of a country to practice their capacity for innovation?

People do innovate in their everyday life, but are there also formal support systems whereby innovation is encouraged to take place? In the Indian context, other than industries, there are various design and technology (D&T) educational institutions that encourage students to work on innovative projects. Apart from D&T education at the tertiary level, there exist few opportunities for school students to exercise their creativity, such as science fairs and competitions. Design for Change (DFC) is another initiative that encourages children to identify local problems and provide solutions for them. The National Innovation Foundation (NIF) website (http://nif.org.in/) is one such initiative maintained by the government of India. It was founded in the year 2000 with support from Department of Science and Technology (DST), India and showcases innovations/solutions provided by school students and adults to a range of problems that they themselves have identified or chosen to work on (NIF, 2015). A lot of innovation happening in India at the grassroots level is a result of the work of people who are not formally trained in D&T education. A list of innovations is provided in the 'awards' section of the website; adult innovations are listed in 'Biennial' award function sub-section (NIF, Biennial, 2015) and student innovations are listed in 'IGNITE' award function sub-section (NIF, IGNITE, 2015). Our inquiry was particularly motivated by the question, "What are the problems identified by adults and children independently and what are the differences in the kinds of problems identified by young innovators and those identified by adult innovators." These questions are important from the perspective of design and technology (D&T) education, as one aspect of D&T education involves engaging with authentic problems, where individuals can select their own problems. This study can help understand the limitations in problem identification.

Innovation, problem solving and problem identification

Problem solving is an important aspect of innovation. Often some new product may be created when a problem in an existing state of affairs is solved with a solution that is unique. However, in recent literature on innovation, besides problem solving the ability to 'identify or find problems' is being considered important for creativity and innovations (Runco, 1994). According to Polanyi (1958), "to recognize a problem which can be solved and is worth solving is in fact a discovery in its own right" (p.120). Researchers have found a correlation between problem finding and verbal divergent thinking tests, however, divergent thinking tests may not be a good indicator of real-world creative performance. Okuda, Runco and Berger (1991) have shown that there is a greater correlation between real-world problem identification and creative accomplishment than with performance on tests of divergent thinking. Other researchers have emphasized the link between real-world problem construction with quality and originality of solutions (Reiter-Palmon, Mumford, Connor & Runco, 1997).

In the Indian education scenario from school to graduation, learners are expected to solve problems that are defined by a teacher, or presented in educational materials. It is rare for a student to be asked to identify a problem herself. Students enrolled in design education at graduate and post-graduate level do get an opportunity to work on problems that they themselves select. But here too, the freedom to identify problem is exercised only in a few select projects. Since D&T education does not exist at the school level in India (Ara, Chunawala, & Natarajan, 2013), the scope of learning to identify problems is limited in the school going population, even though to some extent, a few teachers at their individual level may try to encourage students to identify problems in a presented scenario or problem context. In recent years, there has been an emphasis on inquiry-based learning where students do get to work on problems defined by themselves (Friesen & Scott, 2013). But this practice too, may be confined to only a few institutes in India that are not accessible to a vast majority of students. In such a scenario, we wondered about situations where students could choose to identify problems on their own and also suggest solutions to these problems. What differences would there be between adults and children, if both identified problems independently? This was the question that inspired us to commence this study.

Problem situations have been sub-divided into three main types; presented problem situation, discovered problem situation and created problem situation (Getzels, 1979). A 'presented problem situation' refers to those situations when problems are presented to an individual by another agency or person. The regular tests that happen in classrooms where a teacher presents problems to students to solve is a typical example of a 'presented problem'. Discovered problem situation refers to contexts when an individual discovers an existing problem. Such problems can be discovered by people who are practitioners of a field, for example a mechanic discovers a problem in the spark plug which is preventing a car engine from starting. The "created problem situation" is when an individual creates a problem situation when no problem exists. Such problems can be devised by persons who want to experiment and explore unknown situations. Here one can take an example from the history of technology. The Wright brothers had successfully mastered the art of flying an engine-less glider and had performed about a thousand flights without crashing even once. Their decision to add an engine to the plane did not arise from any problem experienced by them in their existing glider. Instead it was an attempt to challenge the limits of what their existing glider could do. We feel that the kinds of problems that are addressed in the NIF website can be classified as either discovered problems or created problem situations.

An advantage of identifying problems oneself could be related to motivation to solve the problem. Deci and Ryan (1985) in their cognitive evaluation theory which is a subset of self-determination theory have emphasized intrinsic motivation. According to them, when people experience themselves as initiators of their own behaviour, they select desired outcomes and find out alternative means to achieve them. Students too may be motivated to approach a problem that they are instrumental in selecting. This view is supported by Vygotsky, who observed in his studies that children's creative writing vastly improved when they were asked to write on topics they felt deeply about rather than on topics that were given to them by the instructor (Vygotsky, 2004). The freedom to choose and identify a problem maybe one of the essential elements in development of creativity. Hence the study of instances where problems are identified by individuals (both children and adults) was undertaken.

Expert-novice differences in problem solving and problem identification

Adult and children responses in design or problem solving can be looked at from the lens of expert-novice differences, with experts having more knowledge and strategies to organize knowledge. According to Yuan et. al. (2014), experts can perform tasks involving problem solving faster and more precisely than novices. However, they mention an "inverseexpertise effect" which suggests a contrary view where novices seem to perform equally or better than experts in solving certain type of problems (Adelson, 1984). In a study on expert-novice differences in problem identification, Dixon found that expert design engineers were able to identify core problems much faster than novices and thus could spend more time solving the problem as compared to novices (Dixon, 2011). Moreover Chi, Feltovich and Glaser (1981) found that there are differences in expert and novices in how they identify problems and sort them into different categories. While experts categorize problems according to basic principles involved, novices categorize them according to literal features of the problem. These studies have focused on how experts and novices solve problems and how they identify problems. However, in our study concerned with the domain of innovation, we feel that it is difficult to label adults or children as experts or novices mainly because this group that innovates is a very limited select group. While the potentiality to innovate may be present in all of us, the act of actually designing and innovating is rare. Our focus in this study was on the types of problems identified by adults and children to work on. We compare the various categories of problems identified by these two groups of innovators in India, who worked independently without any design brief from any external agency.

Data collection

The NIF showcases innovations at two levels. They organize annual competitions among school students wherein innovative solutions are to be presented along with the problem that prompted these innovations. It also showcases innovations by adults at grassroots levels from all across India. Data of both student and adult innovation is available on the NIF website (record collected from 2001 onwards). For the purpose of our study we tabulated the list of innovations for both children (school students) and adult group for 3 years 2015, 2013 and 2012. Data for 2014 for adults was not available on the website and hence we did not include this year in our sample.

Table 1: Number of innovations showcased on the NIF website for the years 2015, 2013 and 2012 (the biennial issue) for adults and students

	By adults (above 18 years) Biennial award		**By school students (below 18 years) IGNITE award**		**Total**
	innovations	innovators	innovations	innovators	
2015	35	46	30	37	
2013	35	42	28	43	
2012	41	44	26	34	
Total Innovations	111		84		195
Total Innovators		132 (117M, 15F)		114 (81M, 33F)	246 (198M, 48F)

The entries in the adult section were mostly from people dwelling in rural areas, (Abrol & Gupta, 2015) while the entries in the student sample belonged to all sections of society. In both the cases, students and adults, and totally too, the number of innovators is larger than the innovations as more than one person may have collaborated on an innovation.

We find the total innovators to be higher in the adult population as compared to the student population. This statistic (Table 1) we find counter-intuitive as there is a common perception as well as studies to support the view that children are more creative than adults and that this creativity tends to reduce with age (McGarvey, 1992, 2001). These views will be explored later in the discussion section. Of the total number of innovators, there were 198 males and 48 females. Why there were so few female innovators requires a separate investigation. But an interesting point to note is that while there were less student innovators, the number of adult female innovators was less than half the number of student female innovators (Table 2).

Table 2: Female innovators for adult and student groups

Female innovators	**adults (above 18 years) Biennial award**	**school students (below 18 years) IGNITE award**
2015	9	12
2013	4	13
2012	2	08
Total	15	33

An interesting result that has emerged from the data in Table 2 is that while more innovations were listed by adults than students in total, there were more 'female student' innovators than 'female adult' innovators. Even this result requires further investigation.

Since there could be many possible reasons for this difference between the number of adult and children innovations, we focused on the additional data provided regarding each innovation; such as, gender of innovator, place of origin of the innovators, the name given to the innovation and the description of the innovation. We also decided to code these innovations on the basis of the category of problem areas they addressed. The method of qualitative data analysis that we undertook will be detailed in the next section. Table 3 depicts the information of one innovation as an example, but we have used letters instead of the names of the innovators.

Table 3: Specimen of data collected from National Innovation Foundation (NIF) website

Year	Innovator	Place	Innovation	Description	Category/Code
2015	SG (f) and NG (m)	Midnapur, West Bengal	Herbal medicine for respiratory distress in poultry	Innovation to cure respiratory problem in birds	Medicine

Method

The innovations presented on NIF website have been analysed for various innovators seeking external government support for enterprise building, by Abrol and Gupta (2015). They grouped the innovations under a few categories to characterize the fields of knowledge and domains of application that these innovations addressed such as mechanical engineering, masonry etc. As we scrutinized the data of innovations, we found that innovations could be grouped together into different categories based on a criteria of 'problem area identified' instead of 'field of knowledge'. According to us, 'field of knowledge' is different from 'problem area identified' because a person can use mechanical engineering knowledge, which is a field of knowledge in varied problem situations, say, in construction, in designing machines for farming, in designing a vehicle etc. The innovators in this study also had less experiences in 'fields of knowledge', but nevertheless they had identified some problems to work on and it is these identified problems that we are interested in.

Additionally, the research literature citing the parameter of flexibility in various tests for divergent thinking refers to the variety of categories or domains the problem solutions are related to (Dippo 2013). For example, solutions could be linked to many different kinds of categories – such as metals, nature, fabric, health, transport etc. The parameter of flexibility and other aspects of divergent thinking such as fluency (thinking of as many uses of an object as possible), originality (how uncommon are the uses given) and elaboration (how detailed are the uses described) are usually applied to evaluate responses of individuals to problems. But in this paper, we attempt to apply the criteria of flexibility to the total list of innovations produced by two groups of innovators; adults and student.

Our attempt at coding the innovations and arriving at categories of problems in a systematic way involved “many iterations of re-coding and re-categorizing” (Saldana, 2014). The method of coding we used was attribute coding and the primary attribute we used for categorizing was “the context of use” of the given innovation. Each innovation addresses some context of use, for example, a medicine that heals a human or animal patient (medicine), or a vessel used for cooking (kitchen). We thus tried to have a single code for the problem domain that each innovation addressed. The process of coding was manual and the problem domains of the innovations for years 2015, 2013 and 2012 are presented in Table 4.

Table 4: Total Number of Categories (problem domains or contexts of use)

Category: Description (innovation in a particular context)	
1. Agriculture (*gardening)*	12. Windmill
2. Health	13. Tree climbing
3. Construction	14. Drilling machine
4. Kitchen (*cooking)*	15. Pest control
5. High Yielding Variety crops/*seeds*	16. Vehicle
6. Tool/instrument *design*	17. Signalling
7. Electronics	18. Quality control
8. Disability	19. Cleanliness
9. Safety/protection	20. Prohibiter
10. Textiles	21. Electrical
11. Water heating/cooling	22. Miscellaneous

Thus, a total of 21 categories or problem domains were identified. The innovations that could not be categorised or which belonged to a fuzzy category were put in a category termed miscellaneous. Three coders (S, R and A) independently sorted the innovation into these categories. For each year and each group, if all three sorters found even one innovation to place in a category then and only then it was counted as a category for that group and year. For example, if rater 1 identified 4 innovations under category of 'Quality control', rater 2 identified 3 innovations under this category and rater 3 identified only 1 innovation in this category, then it was concluded that 'quality control' is a category that innovators in the group have worked on. However, if the 3rd rater did not rate even a single innovation under category of 'quality control', then this category was not counted for that group in a particular year. We found that even though the raters worked independently, there was consensus about categorising innovations in the categories in a majority of the cases. The number of categories of adult and student group innovations were analysed for comparing the 'diversity in problem areas' identified by both groups. No qualitative judgments were made on a single innovation of an individual.

Results

In Table 5 we present the total number of categories for the 3 years. When doing this only non-repeating categories were added. The total number of innovations in each category as rated by the raters S, R and A for the 3 years are given in Table 6.

Table 5: Total number of categories in adult and student group for year 2015, 2013 and 2012.

	Adult 2015	**Std 2015**	**Adult 2013**	**Std 2013**	**Adult 2012**	**Std 2012**	**Total Adult categories over the 3 years**	**Total Student categories over the 3 years**
Categories	10	9	12	8	13	7	**16**	**13**

The results from Table 4 indicate that adult innovations spanned more problem categories (16) than categories that were identified by student innovations (13) for the three years 2105, 2013 and 2012 combined. For every year too, adult innovations were in more categories. For 2015, adult innovations were in 10 categories while student innovations were in 9 categories. Similarly, the 2013 innovations by adults could be placed in 12 categories and those by students in 8 categories. And in the year 2012, adult innovations were found in 13 categories and student innovations only in 7 categories. We also see that as we progress from 2012 to 2015, the gap between adult and student innovations is gradually decreasing. But we are not sure whether this reduction in gap is a general trend or just a coincidence.

Table 6: Number of innovations in each category for adult and student groups of 2015, 2013 and 2012 (by raters S, R and A)

Category	Adult 2015			Std 2015			Adult 2013			Std 2013			Adult 2012			Std 2012		
	S	R	A	S	R	A	S	R	A	S	R	A	S	R	A	S	R	A
1. Agriculture	6	7	5	6	6	7	9	11	9	*	*	*	6	5	6	*	*	*
2. Health	10	10	10	3	2	4	5	5	5	*	*	*	4	4	4	*	*	*
3. Construction	3	2	3	*	*	1	1	1		*	*	*	*	*	*	*	*	*
4. Kitchen/Cooking related	4	4	4		1	1	4	4	4	1	1	1	6	6	6	1	1	1
5. High Yielding Variety	7	7	7	*	*	*	3	3	3	*	*	*	5	5	5	*	*	*
6. Tool/instrument	2	1	1	3	1	1	2	1	3	1	3	2	3	3	4	*	*	*
7. Electronics	1	1	1	*	*	1	2	2	2	5	3	7	1	1	*	3	4	3
8. Disability	2	2	2	3	5	3	1	1	1	2	2	2	*	*	*	1	1	1
9. Safety/protection	*	*	*	3	3	3	*	*	*	2	3	*	1	1	1	2	1	2
10. Textile	1	1	1	*	*	*	1	1	1	*	*	*	1	1	1	*	*	*
11.Water heating/cooling	*	*	*	*	*	*	2	2	2	*	*	*	*	*	*	*	*	*
12. Windmill	*	*	*	*	*	*	2	2	2	*	*	*	1	1	1	*	*	*
13. Tree climbing	*	*	*	*	*	*	1	1	1	*	*	*	1	1	1	*	*	*
14. Drilling machine	*	*	*	*	*	*	*	*	*	*	*	*	2	2	2	*	*	*
15. Pest control	*	*	*	*	*	*	2	2	2	*	*	*	3	3	3	*	*	*
16. Vehicle	1	1	1	1	2	2	*	*	*	5	3	6	1	1	1	2	2	2
17. Signalling	*	*	*	1	2	1	*	*	*	1	1	1	*	*	*	1	1	1
18. Quality control	*	*	*	5	1	1	*	*	*	*	*	*	*	*	*	*	*	*
19. Cleanliness	*	*	*	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
20. Prohibitor	*	*	*	1	1	*	*	*	*	3	4	4	*	*	*	8	8	8
21. Electrical	*	*	*	*	*	*	*	*	*	3	3	3	1	1	1	*	*	*
22. Miscellaneous	2	3	3	1	3	3	*	*	*	1	1		1	2	1	3	6	3

Reliability

The reliability of our categorisation was tested by a quantitative method of correlating the number of agreements between the 3 raters (S, R and A) divided by the total number of categories. The percentage Inter Rater Reliability (IRR) method was used for calculating the agreement among 3 raters. The final scores were the mean of the 3-different set of comparisons between the raters i.e. S-R, R-A and S-A.

Table 7: Percentage reliability score for 2015, 2013 and 2012 categories.

	2015	**2013**	**2012**
IRR score	.84	.84	.92

The percentage of agreement among the raters for the categorization of the data of 2015, 2013 and 2012 is high; more than 80% (Table 7). A limitation of percentage IRR is that in some cases, it ignores the agreement that could have happened purely because of chance and not due to agreement on the categories between raters. But such cases are more likely when number of categories are less. With 22 categories, the possibility of agreement by chance in many cases reduces and may be less significant.

Interpretation of results

The immediate inference drawn from the available data is that there were a greater number of problem categories (Table 4) in adults' innovation (16) than in school students' innovations (13). The differences in the adult and student group regarding the categories they worked on can be seen in Table 8.

Table 8: Comparison of differences in problem categories of innovations by adults and students for the 3 years combined

Innovation Category	**Innovations by adults**	**Innovations by students**
Agriculture	**20**	**7**
Health	**19**	**5**
Construction	3	0
Kitchen/Cooking related	**14**	**2**
High Yielding Variety	**15**	**0**
Tool/instrument	9	7
Electronics	**4**	**6**
Disability	3	6
Textile	2	0
Vehicle	**2**	**4**
Water heating/cooling	2	0
Windmill	3	0
Tree climbing	2	0
Pest control	6	0
Safety/protection	**1**	**4**
Drilling	2	0
Signalling	***0***	***7***
Quality Control	***0***	***5***
Cleanliness	*0*	*3*
Prohibitor	***0***	***14***
Electrical	1	3
Miscellaneous	3	6

A marked difference between the two groups was that some categories reported by a group were totally absent or limited in the other group. For example, the most common areas of innovation by students were related to 'prohibition' of an undesirable action, also other categories found in the student group, such as, 'quality control' (indicating quality of fruits), 'signalling' (signal to tell if car keys are left in the car) and 'cleanliness' (overturning seat for dirty benches in park. (http://nif.org.in/innovation/reversible-benches-at-public-places/863) were not found in adult innovations. Some examples of the 'prohibition' category innovations were; retractable spikes before zebra crossing that emerge when the traffic signal turns red to prevent vehicles from signal jumping, a chair with sensors at appropriate places which alerts the user if he/she sits in a bad posture and permits one to sit only in a correct posture; a device fitted in cars that prevents people from driving without a license. These examples all relate to some aspect of human behaviour and students have attempted a technological fix to correct the same. This is a very interesting category of problems identified by students which was totally absent in adults. Perhaps, the experience of the adults prevented them from crossing the boundary of technology related problems, while children had no such limits.

Some categories of problems found in adult innovations that were totally absent in the student group were, 'construction', 'textiles' and 'high yielding variety seeds', 'tree climbing', 'water heating/cooling', 'windmill' and 'pest control'. The possible reasons for these differences in student and adults categories of innovations are discussed in detail in the next section.

Discussion

There are studies on differences in creativity among children and adults which suggest that children are more creative than adults. There is also a perception among lay people that creativity is higher in children. Studies on creativity of students have reported a drop in creativity with age and schooling. Blake and Giannangelo (2012) found a reduction in divergent thinking from 98% to 32%, as age progressed from 3 years to 8 years, and from 10% to 2% from ages 13 to ages 25. The criteria for judgment of creativity in these tests is often divergent thinking, which involves tasks that require thinking of alternate uses of an object (Guilford, 1971). If children as a group are more creative, then more 'variation' in categories from a dataset of children's innovation should emerge. However, the dataset that we have collected from the NIF website, shows more variation in the innovation categories in adults as compared to the student. We also saw qualitative difference in the categories of problems identified by adults as against those identified by school students. The support for our findings comes from the contrast of the experiences of adults and children as explicated by Vygotsky:

> "We know that a child's experience is vastly poorer than an adult's. We further know that children's interests are simpler, more elementary, and thus also poorer; finally, their relationship to the environment does not have the complexity, subtlety, and diversity that characterizes the behaviour of adults, and these are the most important factors that determine the workings of the imagination. (Vygotsky, 2004, p. 26)"

A study by Wu, Cheng, Ip and McBride-Chang (2005) looked at age difference in creativity and related these to task structure and knowledge base. They suggest that when tasks are knowledge-rich, experience would play an important role in creativity but not if the task does not require much knowledge. Other existing research shows that creative thinking is a universal ability that can help adults manage satisfying lives and that is increasingly in demand in the workplace (Kerka, 1999; Hickson & Housley, 1997; Flood & Phillips, 2007). Hence it cannot be presumed that creativity is only a domain for children. Adults may also have equal if not more access to developing this skill provided it is not thwarted by social environmental factors (Amabile, 1998).

Differences in problems identified by adults and children

In terms of kinds of problems identified in both adult and student groups, we see that adult innovations contained most categories related to 'Agriculture', 'Health' and 'Cooking'. This could be a reflection of their predominant experiences of farming in a rural context. For example, "RV" is the son of a farmer and is skilled in repairing farm implements and equipment. He had to dropout from college, to join his father on their farm and thereby gained experience in various aspects of farming and produced simple innovations regularly. The innovation that got him noticed by NIF was 'sugarcane bud planter machine' which automates the process of planting sugarcane buds (http://nif.org.in/innovation/sugarcane-bud-planting-machine/796). Figure 1.

Figure1(from NIF)

Figure 2 (from NIF)

Since many people in rural contexts also have experiences of growing/using herbal medicinal plants, there were a large number of innovations related to health in the adult group. For example, “BB”, who helps her husband in agricultural activities innovated a herbal medicine for treating diabetes (http://nif.org.in/innovation/herbal-medication-for-diabetes/800). Similarly, 'cooking' related innovations were also prominent in the adult groups, such as, the 'community rice cooker' innovated by PL (http://nif.org.in/innovation/community-rice-cooker-/770). Figure 2.

The predominance of 'prohibition' related innovations from students could be attributed to the restrictions that students experience in schools or at home. One example of such an innovation was a 'device for preventing people from driving without a license'. The innovator had suggested incorporating a slot near the vehicle’s ignition to insert the driving license. The system would stop anyone from driving (Figure 3) if the license is not present, is invalid or has expired (http://nif.org.in/innovation/preventing-people-from-driving-without-a-license/562).

Figure 3 (from NIF)

Figure 4 (from NIF)

Another category common among students but not found in adults was the category of 'signalling'. This was similar to prohibition, but the difference was that the signal would allow a person the chance to decide the future course of action after an undesirable action has taken place and to prevent further undesirable events from happening. For example, a signalling system that reminds the owner with a phone call if he/she has left the car keys in the car, developed by CK (Figure 4),(http://nif.org.in/innovation/reminding-the-owner-if-keys-are-forgotten-in-the-vehicle/633) aims to prevent the owner from leaving the car keys in the car, though the signal takes place only after the action has occurred. These problems identified by the students could be related to previous experiences of students, who in Indian context are prevented by parents from making mistakes or doing 'wrong' actions. The student may not have had the exact experience of driving without a license, but they are simply selecting all the possible 'wrong' things that they see people being punished for and they want to create an innovation to prevent some wrong thing from happening. Thus, students' innovations can also be aligned with Vygotsky's explanation that imagination also takes its clues from experience.

We can clearly see that the problems identified by students in the category of prohibition, signalling and cleanliness are aimed towards correcting a presumably undesirable human behaviour (undesirable according to the perception of the innovator). Some of these unwanted behaviours or rather habits include; not concentrating in classroom, forgetting car keys inside the car, not sitting properly on chair etc. If we look carefully, these are problems or rather not problems but actions conducted by humans by their choice or according to their personal life conditions. They have a psycho-social dimension to it. But the novice innovators are attempting to solve these ‘problems of bad behaviour’ by proposing some technological gadget. This shows the underlying belief of the novice innovator that people have bad habits and behaviours and these can be ‘corrected’ by inventing some device or gadget. This issue does not exist with expert innovators because their focus is on improving some existing technological artefact and not human conduct. From this we understand that novice innovators are not able to distinguish human behaviour related issues and problems in a technological artefact.

There are many contradicting studies about whether technology can change human behaviour or not. These studies focus on showing the effect of technology on humans (Safwat, Adel, George & Sobhy, 2012). But whether the research is in favour or opposed to technology’s potential for changing human life, these studies do not claim that the aim of technology is to correct wrong human behaviour even though behaviour may change as a side effect of technology and that can go in any direction, desirable or undesirable. But for most novice innovators, changing human behaviour for the better (according to the perception of innovator), seems to be the primary goal and power of technology.

Conclusion

Problem identification is an important aspect of problem solving and innovations. A diverse range of problems can be identified when individuals have the freedom to work on the problem of their choosing. Our study indicates that adults may be able to identify a range of problems greater than students, however, some categories in the students' group were unique. For example, a student had an innovation related to a 'mechanism for relocating clouds in rain deprived areas'. There was no other innovation addressing this issue; that is, water shortage which is a perennial problem in India. Further research needs to be carried on to understand the process of problem identification and how freedom in problem identification can affect creative solutions to a problem. The data about student female innovators being more than double the number of adult female innovators also is an indicator of societal conditions that may be more restrictive for females than males.

The study supports the idea that diversity of experience leads to diversity of problems identified. If teachers are to lead students toward exploring their creative potential, then teachers may need to have experience of diverse problem areas even within a single domain of expertise. Students also need to be exposed to a variety of experiences, from as many diverse areas as possible as their imagination and creativity may be limited by the kinds of experiences they have.

We have seen from the predominant category of problems identified by novices, that they conflate problem with an artefact or situation with problem with a human being. 'A child not concentrating in class' is identified as a problem by a novice innovator that can be solved by some gadget. While such problems are actually dealt with by psychologists and social scientists in real world, such examples show that novice innovators who work on self-defined problems, may not be in a position to distinguish a human related problem with a technological problem and may attempt to solve all problems with technology only.

Students of design and technology need to be sensitized about, not just what technology can achieve, but also about the limits of technology and the category of problems that technology can address and those that technology cannot address and that there are certain category of problems, that exist outside the purview of providing a technological solution. The question that emerges is how can D&T students be sensitized to these psycho-social or socio-technological problems. This category of problems can constitute a different level of challenge for design and technology educators and students. This may have scope for opening up creative innovations that address psycho-social and socio-technological issues that do not have a conventional technological solution in the form of some device or gadget.

References

Adelson, B. (1984). When Novices Surpass Experts: The Difficulty of a Task may Increase with Expertise. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, Vol 10(3), 483-495

Amabile, T. (1998): How to Kill Creativity. Harvard Business Review. Retrieved June 16, 2017 from https://hbr.org/1998/09/how-to-kill-creativity.

Abrol, D., & Gupta, A. (2015). Understanding the Diffusion Modes of Grassroots Innovations in India: A study of Honey Bee Network Supported Innovators. *African Journal of Science, Technology, Innovation and Development.* Vol. 6(6), 541-552.

Ara, F., Chunawala, S., & Natarajan, C. (2013). Investigating Indian Elementary and Middle School Students' Images of Designers. *Design and Technology Education: An International Journal, 18(2),* 50-65.

Blake, S., & Giannangelo, M. D., (2012). Creativity and Young Children: Review of Literature and Connections to Thinking Processes, in O.N.Saracho (eds). *Contemporary Perspectives on Research in Creativity in Early Childhood Education.* University of Maryland, North Carolina: Information Age Publishing, pp 293-318.

Chi, M. T. H., Feltovich, P. J. and Glaser, R. (1981), Categorization and Representation of Physics Problems by Experts and Novices. *Cognitive Science,* 5: 121–152.

Deci, R. M., & Ryan, E. L. (1984). *Intrinsic Motivation and Self-Determination in Human Behavior*. University of Rochester. New York. Springer

Dixon, R. A. (2011). Experts vs Novices: Differences in how Mental Representations are used in Engineering Design. *Journal of Technology Education*, 47-65.

Dippo, C. (2013). Evaluating the Alternative Uses Test of Creativity. *Proceedings of the National Conference on Undergraduate Research (NCUR).* University of Wisconsin La Crosse, WI 427-434.

Flood, M., & Phillips, K. D. (2007). Creativity in Older Adults: A Plethora of Possibilities. *Issues in Mental Health Nursing,* Vol. 28, 389-411.

Friesen, S. & Scott, D. (2013). Inquiry-Based Learning: A Review of the Research Literature. *Alberta Ministry of Education*. Retrieved, May 2016, from http://galileo.org/focus-on-inquiry-lit-review.pdf.

Getzels, J. W. (1979), Problem Finding: A Theoretical Note. Cognitive Science, 3: 167–172.

Gallagher, P. (2012). *Innovation as a Key Driver of Growth and Competitiveness. National Institute of standards and Technology*. Retrieved, Dec. 2016, from https://www.nist.gov/speech-testimony/innovation-key-driver-economic-growth-competitiveness.

Guilford, J.P. (1971). *The Nature of Human Intelligence*. New York: McGraw-Hill.

Hickson, J., & Housley, W. (1997). Creativity in Later Life. *Educational Gerontology*. Vol. 23 (6), 539-547

Kerka, S. (1999). Creativity in Adulthood. *Eric Digest.* No. 204.

NIF, Biennial (2015). *Biennial.* National Innovation Foundation. Retrieved June, 2016, from http://nif.org.in/biennial-award-function/15.

NIF, Ignite (2015). *Ignite.* National Innovation Foundation. Retrieved June 2016, from http://nif.org.in/ignite-award-function/16.

Okuda M.S, Runco, M.A, & Berger D. (1991), Creativity and the Finding and Solving of Real-World Problems. *Journal of Psychoeducational Assessment,* vol. 9(1), 45-53

Polanyi, M. (1958). *Personal Knowledge.* Chicago: University of Chicago press.

Reiter-Palmon, R., Mumford, M.D., O'Connor B.J., & Runco, M.A. (1997). Problem Construction and Creativity: The role of Ability, Cue Consistency, and Active processing. *Creativity Research Journal, 10,* 9-23.

Rosenberg, N. (2005). *Innovation and Economic Growth*. OECD. Retrieved Nov. 2016, from https://www.oecd.org/cfe/tourism/34267902.pdf.

Runco, M.A., (1994). *Problem Finding, Problem Solving and Creativity*. New Jersey: Ablex Publishing.

Safwat, C., Adel, H., George, M. and Sobhy, S. (2012). *The Effect of Technology on Human Behavior (A Case Study on BBC Secondary School and The British University in Egypt)*. Faculty of Economics and Political Science, Department of Statistics. Cairo University.

Saldana, J. (2012). *Coding Manual for Qualitative Researchers*. London: Sage Publications.

Vygotsky, L. (2004). Imagination and Creativity in Childhood. *Journal of Russian and East European Psychology, 42(1),* 7-97.

Wilson, V. & Harris, M. (2004). Creating Change? A Review of the Impact of Design and Technology in Schools in England. *Journal of Technology Education, 15(2),* 46-65.

Wu, C.H., Cheng, Y., Ip, H.M., & Chang, M. B. (2005): Age Differences in Creativity: Task Structure and Knowledge Base, *Creativity Research Journal, 17(4),* 321-326.

Yuan, J. T. J., Kong Y. K., Parveen, H., Zhixiang, H., Rajasekaran, G., Behera, K.J., Sanaei, R., Otto, N. K., Otto, H. K. (2014). An Overview of Design Cognition between Expert and Novices. *International Conference on Advanced Design Research and Education ICADRE14*. Singapore (pp. 16-18)

Balancing Curriculum Intent with Expected Student Responses to Designerly Tasks

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Abstract
Design activities form an extensive part of design and technology education with a link being posited within the pertinent literature between the cognitive activity of learning and the cognitive activity of design. It is therefore critical that design educators' understand the effects that design constraints can have on the learning process. This paper aims to examine the potential to affect student responses and associated learning from design tasks based on the manipulation of task variables. A study was designed to examine the effects of two modelling systems – one parametric and one non-parametric – on the thought processes and design journeys of the students. The findings suggest that the use of parametric modelling can emphasis student thinking on technical considerations while the use of a freeform moulding CAD system affords a more creative orientation. Qualitative findings demonstrate the capacity of students to select appropriate strategies to complete the design task, further indicating that relaxing design constraints can support student learning in design activities. Considering curricular intentions to develop both technical and creative competencies, this study presents empirical findings illustrating how teachers can strategically design tasks which balance expected student responses with intended learning outcomes.

Key words
graphical education, Design, Modelling, CAD, Learning, Curriculum intent

Introduction
Graphical education was introduced into post-primary education in Ireland within the subject of Art and Drawing in 1923 whereby the graphical component was seen within the section named Mechanical Drawing and Design. The vocational origins of the subject are clearly illustrated through the inclusivity of technical draughtsmanship as an examinable skill, however design was also a core aspect of the subject as shown through its synthesis with art education (Seery, Lynch, & Dunbar, 2011). Examples of design activities within the subject included the design of posters, book covers, abstract compositions and fabrics (SEC, 1970).

Since its inception graphical education in Ireland has undergone a number of educational reforms (Seery et al., 2011) and has evolved into the contemporary subject of Design and Communication Graphics (DCG) at upper post-primary level. As one of the four subjects within the suite of technology education subjects in Ireland (Technology, Construction Studies, and Engineering form the remaining three) the overall agenda of DCG is to contribute to the development of technological capability (DES, 2007a). In conjunction with this, DCG has a number of specific aims and objectives. While a wide variety of specific objectives exist such as developing visuospatial reasoning skills, developing graphical communication skills, and providing a basis for lifelong learning, two clear aims permeate the syllabus: developing creative and designerly competencies, and developing technical expertise (DES, 2007a). Specifically in relation to creativity, DCG aims to "prepare [students] to be creative participants in a technological world" by affording them the opportunity to "express their creativity in a practical and imaginative way, using a variety of forms: verbal, graphic, model, etc." (DES, 2007a, p.5) while simultaneously from a technical perspective students should be "familiar with the principles, concepts, terminology and methodologies associated with the graphics code" and be "able to produce neat and accurate drawings that comply with internationally recognised standards and conventions" (DES, 2007a, p.6). Clearly, the subjects' vocational and creative aims still exist and from a pedagogical perspective it is therefore critical that educators achieve an appropriate synthesis between them. One way this can be facilitated is by balancing expected student outputs with curricular intent through the strategic design of educational tasks which afford specific types of thinking and learning. To contextualise this approach within the subject's intended learning outcomes, its primary goal of developing technological capability must first be explored.

Technological Capability

The concept of technological capability has traditionally been difficult to define (Gagel, 2004). A reason for this lies in the subjectivity in defining and measuring what makes a person technologically capable. Specifically within technology education in Ireland (DES, 2007a, 2007b), technological capability is defined as including:

- The understanding of appropriate concepts and processes
- Skills of design and realisation
- The ability to apply knowledge and skills by thinking and acting confidently, imaginatively, creatively and with sensitivity
- The ability to evaluate technological activities, artefacts and systems critically and constructively

This definition aligns almost perfectly with that of the Scottish Consultative Council On The Curriculum, who define technological capability as having an "understanding [of] appropriate concepts and processes; the ability to apply knowledge and skills by thinking and acting confidently, imaginatively, creatively and with sensitivity; [and] the ability to evaluate technological activities, artifacts and systems critically and constructively" (Scottish CCC 1996, p.7). Gibson's (2008) model provides structure to this definition by describing technological capability as the unison of skills, values and problem solving underpinned by appropriate conceptual knowledge. Black and Harrison's (1985) model adds an additional dimension to the term through their recognition of the dichotomy of designing and making. They define technological capability as being able "to perform, to originate, to get things done, to make and stand by decisions" (Black and Harrison 1985, p.6). Despite the variances in each definition, there are persisting commonalities. One trait which is regularly alluded to is the capacity to problem solve within the technological context. Within the confines of DCG and reflecting the aims of the subject, problem solving activity is encapsulated within two interconnected forms; geometric problems and design orientated problems. The focus of this paper is to explore how, by controlling variables associated with design realisation in a design task, student output and associated learning outcomes can be manipulated to align more with creative competencies or technical skills.

Designerly Thinking and the Cognitive Capacities Espoused within DCG

Design in education has been an area of substantial interest over the past number of decades. The 1970's saw an increased understanding of the design capacity of humans (Archer, Baynes, & Langdon, 1976; Cross, 1979) resulting in discussion about the necessity for the inclusivity of design in general education (Stables, 2008). Within DCG, design activity is conceptual in nature, however as the subject is within the suite of Technology subjects, recognition is given to the development of technological capability (DES, 2007a). Reflecting Black and Harrison's (1985) model, this recognition can be seen in that conceptual design is typically carried out with a view towards making.

Archer (1992, p.8) describes design as 'envisaging-what', differentiating it from technology which he offers the comparison for as being 'knowing-how' and further identifies design as embodying an "entirely different mental discipline". This mental discipline is broadly described as designerly thinking. Stables (2008, p.8) identifies humans as being "designerly by nature" in that being designerly is "a capability that exists as innate potential". Stables (2008, p.8) further discusses the derivation of the term 'designerly' from a culmination of human abilities, three of which being of particular importance in its conception; our ability to 'image' things in our mind, our ability to both cognitively and externally manipulate those images and our ability to utilise those images in the creation of future realities. Baynes (1992) posits that 'design intelligence' could be a unique form of intelligence. He argues that if it were, design intelligence would hold the characteristics of being speculative, existing due to the human capacity to form mental representations of ideas, existing socially as models act as representatives for human imaginings, and its content would be derived from the rules of human perception (Baynes, 1992b). Seery (2017) builds on this position by advocating that modelling, one of the core aspects of design, also consists of an element of critique. This dichotomy between speculation and critique mirrors the two aims of contemporary graphical education whereby creative endeavours could be argued to be a more speculative process in comparison to the critical nature of technical skills.

Operationalising Designerly Thinking through Conceptual Design

The nature of design in DCG is conceptual with a view towards manufacture. This consideration for manufacture is achieved through the creation of a CAD model of a design solution. The externalisation of the idea, or modelling, is a critical element of the design process. Baynes (1992b) eloquently describes this process of designing through the three actions of imaging, modelling and communicating. He describes how "people use imaging to visualise or 'see in the mind's eye' [and] they communicate about the things they have visualised by means of models" (p.23). He further suggests the significance of models within the ideation stage of the design journey as models allow for communication with the self and with others.

Archer (1992, p.13) discusses the close relationship between the cognitive activities of designing and learning stating that "the design process is a special application of the learning process". The contemporary position that design can have profound effects on student learning is ubiquitous causing a need for educators who adopt pedagogical approaches underpinned by design tasks to understand the idiosyncrasies pertinent within the implementation of such activities. Perceptually minor details such as the implementation of output constraints could potentially result in the circumvention of the nature of thinking that the design activity was initially employed to elicit.

Study Aim

The aim of this study was therefore to examine if, by controlling the tools which students utilise to externalise design ideas, the nature of their output and associated learning objectives could be manipulated. If it is possible to manipulate how students engage with design tasks, specifically concerning how and what they think about, educators would be better equipped to target specific learning outcomes. Specifically within DCG, students undertaking the subject utilise CAD in the form of SolidWorks as a design tool. SolidWorks is a parametric modelling tool and therefore a fundamentally different CAD system, CRE8 which is a freeform moulding CAD software, was utilised as a comparative to examine the potential effects each had on student thinking. As well as its educational association, another reason CAD was selected as the modelling medium is that previous research illustrates a link between CAD and creativity in designing (Musta'amal, Norman, Jabor, & Buntat, 2012) and therefore it presents an opportunity to examine how tasks can be aligned with both creative and technical competencies.

Method

Participants

The participants for this study (N=15) were selected based on their inclusivity in DCG at post primary level. 13 participants were studying DCG at Higher Level and two were studying the Ordinary Level course. The cohort had a mean age of 15.53 years with a standard deviation of 0.52 years. All participants had previously engaged in a design and technology subject which required the submission of a design portfolio for assessment and this experience suggested a previously developed construct of how the design task included in the study would be carried out.

In order to examine the effect each CAD software had on student thinking, two groups were formed from the research cohort based on their performance in DCG as evidenced through their most resent exam results. This ensured that the ability level of each group as well as the CAD system were controlled allowing for a more valid interpretation of the research findings. The exam contained both a geometric problem solving element and a parametric modelling element. The student's exam results from both sections were calculated and based on their total scores they were stratified between a parametric and non-parametric group so that both groups had near equal average scores. The average result of the non-parametric group was 61.25% and the average of the parametric group was 59.23%. The average result for the entire cohort was 60.3%. Eight students formed the non-parametric group while the remaining seven formed the parametric group.

CAD Modelling Tools

Parametric modelling in the form of SolidWorks was selected to be one tool the students would use to reflect their current educational curriculum. A freeform surface modelling system called CRE8 was chosen as the comparative as it is a 3D design and moulding program and therefore required a fundamentally different approach to modelling. A Novint Falcon is required in conjunction with CRE8. The device provides haptic feedback to the user allowing them to feel their model and manipulate it through touch providing an additional opposing characteristic to a parametric modelling tool. Figure 1 depicts a student using CRE8 and the Novint Falcon to model an organic geometry. When modelling with CRE8, the user first selects an initial geometry and then deforms it to create the desired geometry. Additional geometries are then created relative to this and there are no explicit dimensioning features. The non-parametric group were allocated CRE8 for this study.

Figure 1. A participant using CRE8 and the Novint Falcon to model an organic geometry.

Pre-study training

All students had previous experience of parametric CAD modelling, engaging with it for ten weeks prior to the study which amounted to ten 70 minute lessons. These lessons focused on skill development and modelling solid geometry. The features examined during this time were extrudes, revolves, sweeps, fillets, and chamfers to both add and subtract material. As no student had experience of the non-parametric CAD system prior to the study, a 20 minute demonstration was delivered to the non-parametric group. During this time the group received an overview of the technology followed by each student experimenting individually with the software and hardware while asking questions to clarify any queries as a group. They then participated in individual modelling tasks requiring them to model an organic geometry allowing for the development of personal constructs such as their own capability and the capacity of the modelling tool. Upon completion, the parametric and non-parametric groups were reunited for the beginning of a design task. The reason for the significant time difference in the student's exposure to both CAD systems relates to the number of available features in each and the different approaches to modelling solid geometry. As the non-parametric CAD system only contained a small number of independent commands, the required learning time was small.

Formulating the design task

Doyle (1983) argues that when designing tasks to encourage students to work at a comprehension or understanding level the task must remain ambiguous. The task also needed to be designed to allow for both a parametric modelling solution and for a freeform moulded solution. The concept of a chair was chosen for the task as it would be both familiar yet indistinct and the vague nature of the concept would lend itself to multiple possible solutions from both modelling mediums. The use of a chair as a design stimulus is also commonly used in design research (Buckley, Seery, & Canty, 2017; Goldschmidt & Sever, 2011)

Implementation

The first stage of the design task required students to conceptualise individual design ideas. The students were provided with paper and sketching equipment. No communication was permitted between students to allow individual thought processes to be captured through their sketches and annotations. Students were afforded 30 minutes for this activity.

The second stage of the task required students to complete a modelling plan based around Chester's (2007) 'CAD Workbook' as a pedagogical strategy to encourage the development of strategic knowledge in the students which could be utilised in the creation of their models. Students were instructed to create a plan which could be used to guide the modelling of their designs using their allocated CAD software. No explicit form of graphical communication was required allowing students to select the mode of communication they felt was most appropriate. Designs were allowed to be refined during this time but the overall concept had to remain the same. The purpose of this activity was to require the students to consider their designs under the constraints placed on them through their allocated modelling medium. This activity was run for 30 minutes.

The final stage of the task required students to model their designs using their allocated CAD software. Each student was afforded 30 minutes for this activity. This experience was captured using both a visual (screen capture) and verbal protocol.

Capturing participant responses

Upon completion of the design activity all students were introduced to CRE8 and the Novint Falcon and the parametric group were given the opportunity to explore them through a similar demonstration and modelling exercise as was experienced by the non-parametric group. All students then participated in semi-structured interviews designed to gather feedback on the modelling tools where they were asked about their experiences with them and their perceptions of their uses.

A repertory grid was subsequently implemented to uncover the students' personal constructs related to the modelling tools. This approach was selected to allow for the elicitation of perceptions without researcher bias (Whyte & Bytheway, 1996). When implementing the repertory grids it was decided to include additional modelling mediums which were familiar to the students as comparatives based around Thurstone's (1927) law of comparative judgement. Therefore, sketching, discussion, technical drafting, modelling with rigid materials, and modelling with malleable materials were included. Each modelling medium was evaluated on a number of criteria on a 10-point slider scale (See Table 1). The students completed a questionnaire and the results then automatically populated the repertory grids.

Findings

The results of the ideation stage of the design task illustrate the different approaches taken by both groups (Figure 2). This was seen initially through the modes of communication used with the entire non-parametric group selecting the medium of sketching with annotations while 28.57% of the parametric group selected technical drafting as the most appropriate medium of communication. These took the form of orthographic, oblique and isometric drawings.

The modelling plans further conveyed these opposing approaches, again seeing the non-parametric group continuing to graphically represent their ideas through sketches while 57.14% of the parametric group now relied on text to create the plans. The remaining students from parametric group, who did choose to graphically represent their ideas, displayed them as an assembly guide.

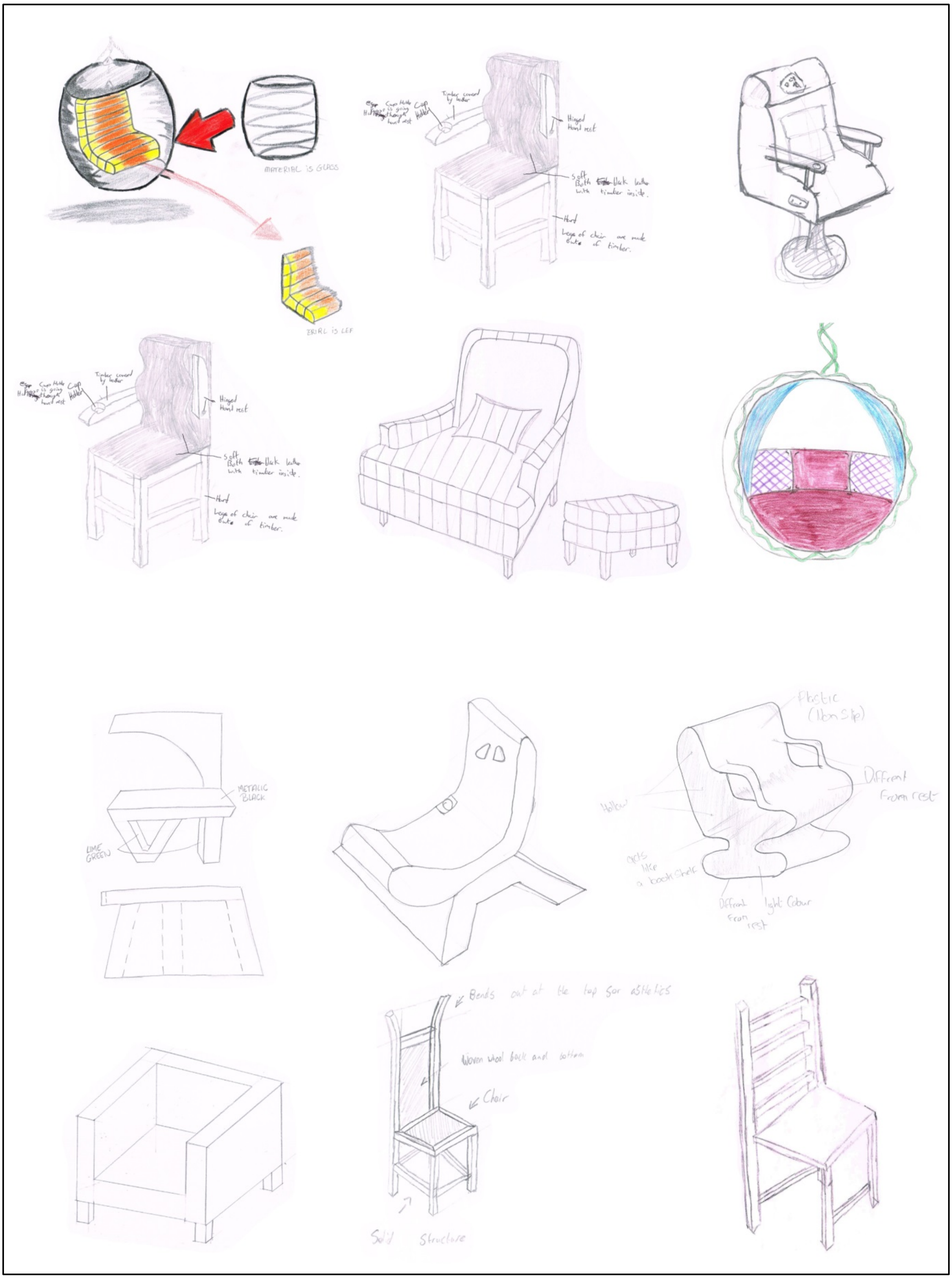

Figure 2. Sample of ideas from the non-parametric group (top 6) and parametric group (bottom 6).

A number of themes were illustrated within the students designs (Figure 2). The parametric groups' designs suggested a dictation by a manufacturing process whereas the non-parametric groups' designs were user focussed. The parametric group designed chairs which were predominantly square in shape. Those that had curves could be modelled by sketching the end view of the chair and extruding it. Reflecting a potential user, the non-parametric group designed chairs that with a more organic form. Three students designed chairs where the primary geometry was a sphere while the remaining students created chairs that were primarily based on curved geometry such as cylinders or they deformed prisms to fit the user.

Further analysis of the designs yielded more insightful findings concerning the influence of each CAD system. In both the conceptual ideas sheets and the modelling plans, the non-parametric group evidenced significantly more depth in their ideas (Figure 3) with more students considering design aspects a greater number of times while the modelling plan activity for both groups evolved into a space where all students viewed their designs in more depth and through more lenses. The only aspect of their designs the parametric group viewed in more frequently was the size of their designs which is posited to be a reflection of the technical nature of parametric driven design.

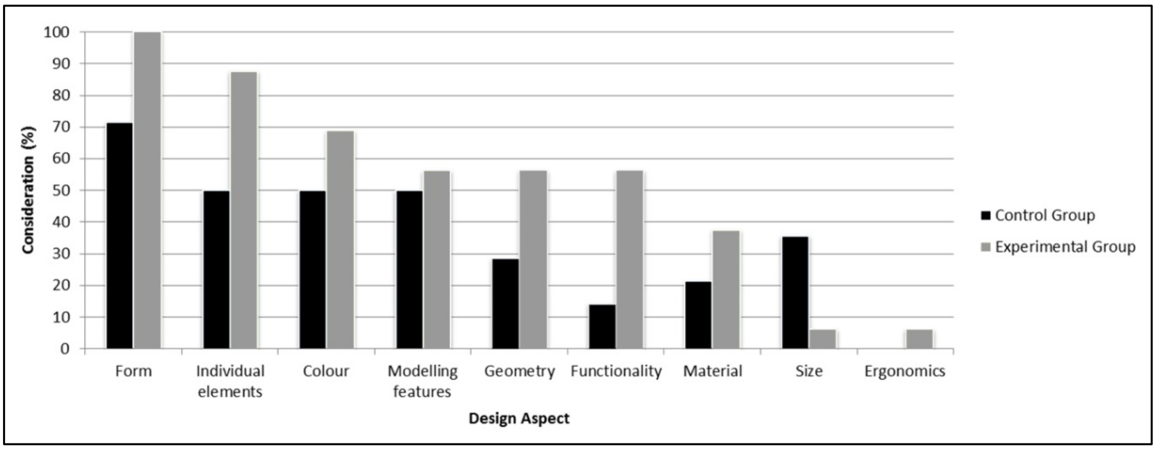

Figure 3. Design considerations from both the ideation and modelling plan stages.

During the interviews the students highlighted their perceptions of each CAD system based on their experiences. The parametric approach was commended for its 'variety' (PT03) of features and 'accuracy' (PT03, PT06) however many negative views were held regard how 'linear' (PT09) it was, it's greater learning time and difficulty level, that you had to have 'certain lines' (PT09) [referring to closing contours, fully defining sketches and the use of construction geometry] and you 'couldn't have wild designs' (PT09) that they had to be 'simple enough' (PT09).

The non-parametric approach also had a mixed response. On a positive level it proved to be "fun" (PT01, PT14), "interesting" (PT01, PT14), "easier than SolidWorks" (PT01, PT07) and that 'you do what you want, what you want to see in the end' (PT07). Criticisms of the non-parametric approach centred around inaccuracy, the 'certain amount of shapes your allowed to use' (PT10) and students initially found the Novint Falcon difficult to control.

All students shared the view that they would have liked to be able to use both on their designs and indicated how they would have done so. Some wanted to begin in parametric modelling to create the initial basic shape and then transfer that model into the non-parametric system to deform it to make it more comfortable, others wanted to start in the non-parametric system to make a moulded starting point which they could dimension and add features to by parametric modelling and more suggested that they were capable of making geometries in both but the copy and paste feature available in the non-parametric system and being able to freely drag geometries would be useful.

The final piece of data gathered was from the repertory grids. Each student indicated their own personal constructs for each modelling tool on a slider scale. The descriptions in the left and right columns indicate the terminology at either end of the scales. For example, 'difficult to learn/develop competency' was at one end of the first scale with 'easy to learn/develop competency' being at the other end. After each student indicated their position on each scale for each modelling tool, average values for each group were calculated. Table 1 shows the mean differences in values between both groups for each of the scales. Following the design activity, the non-parametric group appear to value sketching and modelling with malleable materials more highly than the parametric group while the parametric group in turn value technical drawing and modelling with rigid materials. Both rated the CAD programs and discussions relatively equally. Due to the small sample size, statistical significance testing was not conducted.

Table 1: Repertory grid showing personal constructs of the parametric and non-parametric groups.

	SolidWorks	Novint Falcon	Sketching	Discussion	Physical Modelling *Rigid Materials*	Physical Modelling *Malleable Materials*	Technical Drawing	
Difficult to learn/ develop competency	0.52*	0.57*	0.63	0.98	0.61	0.21*	0.02	Easy to learn/ develop competency
Tedious to do/use	0.23	0.89	0.71	0.32*	1.20	1.75*	1.61	Enjoyable to do/use
Useless	0.25*	0.61*	0.21*	0.80	0.34	1.84*	1.07	Useful
Does not aid in developing understanding of	1.43	0.36	0.50*	0.79	0.46	0.73*	1.04	Aids in developing understanding of
Irrelevant	0.95	0.45	0.29*	0.32*	0.96	0.27*	1.27	Relevant
Complicated	1.11*	1.20*	0.45*	0.16*	0.36	0.38*	0.91	Intuitive
Long learning time	0.39*	0.14*	0.23*	0.16*	2.29	0.57	0.11*	Short learning time
Unhelpful in communicating	0.75	0.02	0.02*	0.00	0.30	1.29*	0.91	Helpful in communicating ideas
Would not use by choice	1.95	0.13*	0.61	0.79	0.68	0.36*	1.79	Would use by choice

Note. * Indicates higher mean values from the non-parametric group. Scores with no asterisk indicate higher mean scores from the parametric group.

Discussion

The findings of this study illustrate that both groups had different approaches to this design task. Considering the variables of ability, task, and CAD systems were controlled for, the empirical evidence from this study therefore indicates that the CAD systems likely caused the variance in student approaches. These findings have many parallels to a similar study conducted by Kimbell, Lawler, Stables and Balchin (2002) in which they examined the use of Pro/DESKTOP (PDT) at post-primary level in England. Kimbell et al. (2002) found that students who used PDT designed in a particular way which was inherently associated with PDT, similar to how in this study the use of parametric and non-parametric CAD influenced students design approaches. From a pedagogical perspective this has significant implications as it highlights the impact that strategic task design can have on student learning and how educators can control variables to influence expected student responses to pedagogical tasks. For graphical education educators specifically, by utilising certain tools teachers can enhance students' creative endeavour or manipulate the same task to be technically orientated. This is important both when considering the aims of graphical education but it can also be applied at an individual student level to address deficits students may have. For example, some students in a cohort may have stronger technical skills and need additional emphasis on creative development while conversely, other students may need to develop higher levels of technical proficiency.

The findings that the parametric group spent more time focusing on the dimensions of their design while the non-parametric group considered all other elements to a greater extent does not necessarily indicate that using CRE8 resulted in a more substantial level of thinking. It does however indicate that overall designs were considered in greater depth. The parametric group may have invested deeply in the consideration of their designs technical specifications whereas the non-parametric group may have examined multiple aspects at a conceptual level. Again, this is a critical implication for educators when designing a task as they may need students to engage with certain aspects of a design task very critically while other aspects, depending on the intended learning outcomes, may only require peripheral consideration.

The results from the repertory grids potentially highlight how the affective domain can be influenced by new experiences. The non-parametric group valued what could be seen as more fluid or conceptual ways of modelling more highly while the parametric group placed more value on technical activities. Unfortunately, similar repertory grids were not carried out prior to the study to identify if this signifies a change in personal constructs but it does provide merit to exploring how educational experiences impact on our value systems and then in turn how these value systems effect our learning. If it is the case that parametric modelling assists in the development of technical values then perhaps a more fluid modelling tool should coincide with this to achieve a balance in adhering to curricular intent. Considering the potential synthesis of multiple modelling tools in practice, the results of this study further indicate the capacity that student have, at least at upper post-primary level, to critically decide the appropriateness of different tool functions for different design stages.

Making decisions pertaining to appropriate modelling tools is a significant skill in relation to design students. The findings from this study clearly illustrated that the students had sufficient capacity to select the appropriate actions to achieve their goals through their identification that a synthesis between both parametric and non-parametric tools would have been the most appropriate way to approach modelling in the design task. Again, this is similar to the study conducted by Kimbell et al. (2002) whereby students identified the capacities of PDT such as its accuracy and its ability to provide a clear visual representation of a design. Considering Crehan et al's (2012) observation that removing explicit design criteria can complement a deep approach to student learning coupled with the capacity to identify an appropriate strategy as evidenced by the students in this study, it is posited that allowing students the capacity to make executive decisions concerning their approaches to design tasks would facilitate their progression and learning within graphical education. A final note relating to giving students more freedom to choose a particular type of CAD system is that students can find learning parametric CAD quite difficult. This was shown both in this study and in the study conducted by Kimbell et al. (2002). The difficulty in learning parametric CAD was discussed more deeply by Kimbell et al. (2002) and with additional evidence they illustrated how this difficulty can have positive effects on motivation and enthusiasm. Specifically, they acknowledge computer-game culture may have a role in this as with both parametric CAD and computer games, difficulty can be regularly faced however when overcome this can have positive motivational effects. This has pedagogically implications as while it is important to design tasks with reasonable levels of difficulty, the challenge posed by parametric CAD is not inherently bad.

Conclusion

This paper has presented empirical findings which demonstrate controlling variables associated with student output can affect student responses. A direct consequence of affecting the actions of students is the manipulation of student thinking. Where there is multiple focuses within a curriculum, such as the aims to develop both creative and technical competencies in graphical education, educators can orchestrate tasks which manipulate student outcome to address different intended learning outcomes. It is apparent in this study that parametric modelling resulted in students taking a more technical approach within a design task while freeform moulding allowed students to work more fluidly and promoted comprehensive user centred design. A more comprehensive knowledge of the affordances of modelling tools can empower teachers to be more scientific in their approaches to student learning by facilitating individual student needs. Additionally, the students within this study identified the appropriateness of working outside the constraints of the design task and with students evidencing this cognitive capacity, confidence is given to allowing students more freedom in their own educational decisions. However, while affording students the capacity to make decisions pertinent to their own design journeys, a careful balance must be achieved to ensure such decisions don’t ultimately result in the circumvention of the learning outcomes which are at the core of the design task.

References

Archer, B. (1992). The nature of Research in Design and Design Education. In B. Archer, K. Baynes, & P. Roberts (Eds.), *The Nature of Research into Design and Technology Education. Design Curriculum Matters: Occasional Paper No. 1* (pp. 7–14). Leicestershire: Loughborough University.

Archer, B., Baynes, K., & Langdon, R. (1976). *Design in general education: Part one summary of findings*. London: Royal College of Art, Department of Design Research.

Baynes, K. (1992a). *Children designing: Progression and development in design and technology at key stages 1 and 2. Learning design: Occasional paper No. 1*. Loughborough: Loughborough University.

Baynes, K. (1992b). Research into primary design and technology. In B. Archer, K. Baynes, & P. Roberts (Eds.), *The Nature of Research into Design and Technology Education. Design Curriculum Matters: Occasional Paper No. 1* (pp. 15–21). Leicestershire: Loughborough University.

Black, P., & Harrison, G. (1985). *In place of confusion: Technology and science in the school curriculum*. London: Nuffield-Chelsea Curriculum Trust and the National Centre for School Technology.

Buckley, J., Seery, N., & Canty, D. (2017). Heuristics and CAD modelling: An examination of student behaviour during problem solving episodes within CAD modelling activities. *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-017-9423-2

Chester, I. (2007). Teaching for CAD expertise. *International Journal of Technology and Design Education*, *17*(1), 23–35.

Crehan, M., Seery, N., Canty, D., & Lane, D. (2012). Constructivist e-portfolios: The use of media in the collecting and evidencing of student learning. In *119th Annual American Society of Engineering Education Conference*. San Antonio, Texas: American Society for Engineering Education.

Cross, N. (1979). Design education for laypeople. *Studies in Design Education Craft and Technology*, *11*(2), 68–72.

DES. (2007a). *Leaving Certificate Design and Communication Graphics Syllabus*. Dublin: The Stationery Office.

DES. (2007b). *Leaving Certificate Technology Syllabus*. Dublin: The Stationery Office.

Doyle, W. (1983). Academic work. *Review of Educational Research*, *53*(2), 159–199.

Gagel, C. (2004). Technology profile: An assessment strategy for technological literacy. *The Journal of Technology Studies*, *30*(4), 38–44.

Gibson, K. (2008). Technology and technological knowledge: A challenge for school curricula. *Teachers and Teaching*, *14*(1), 3–15.

Goldschmidt, G., & Sever, A. L. (2011). Inspiring design ideas with texts. *Design Studies*, *32*(2), 139–155.

Kimbell, R., Lawler, T., Stables, K., & Balchin, T. (2002). Pro/DESKTOP in schools: A pilot research study. *The Journal of Design and Technology Education*, *7*(1), 29–33.

Musta'amal, A. H., Norman, E., Jabor, M. K., & Buntat, Y. (2012). Does CAD really encourage creative behaviors among its users: A case study. *Procedia - Social and Behavioral Sciences*, *56*(1), 602–608.

Scottish CCC. (1996). *Technology education in Scottish schools: A statement of position*. Dundee: Scottish Consultative Council of the Curriculum.

SEC. (1970). *Art and Drawing: Mechanical Drawing and Design: Honours*. M.92, Dublin: State Examinations Commission.

Seery, N. (2017). Modelling as a form of critique. In P. J. Williams & K. Stables (Eds.), *Critique in Design and Technology Education* (pp. 255–273). Singapore: Springer Singapore.

Seery, N., Lynch, R., & Dunbar, R. (2011). A review of the nature, provision and progression of graphical education in Ireland. In E. Norman & N. Seery (Eds.), *IDATER Online Conference: Graphicacy and Modelling* (pp. 51–68). Loughborough: Design Education Research Group, Loughborough Design School.

Stables, K. (2008). Designing matters; Designing minds: The importance of nurturing the designerly in young people. *Design and Technology Education: An International Journal*, *13*(3), 8–18.

Thurstone, L. L. (1927). A law of comparative judgement. *Psychological Review*, *34*(4), 273–286.

Whyte, G., & Bytheway, A. (1996). Factors affecting information systems success. *International Journal of Service Industry Management*, *7*(1), 74–93.

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23.1

The Use of Metaphors as a Parametric Design Teaching Model: A Case Study

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Abstract

Teaching methodologies for parametric design are being researched all over the world, since there is a growing demand for computer programming logic and its fabrication process in architectural education. The computer programming courses in architectural education are usually done in a very short period of time, and so students have no chance to create their own designs. This paper describes a course in which metaphors are used as a teaching methodology in parametric design, in order to let students create their own designs and learn the basic elements of parametric programming language in a short period of time with deductive reasoning. In this course, it was intended to teach visual programming language to undergraduates. Advancing under the metaphor theoretical framework, the students obtained experience in achieving form-finding process for their projects in accord with the certain constraints. Using this methodology, the students, who experienced all design stages from 3D modeling to the digital fabrication, additionally were able to develop their ability for versatile thinking and the use of more than one tool in combination, in the early years of their architectural education.

Key words

metaphors; Parametric Design; Form-finding; Teaching Model; Architectural Education.

Introduction

When parametric design is referred to, two perspectives come to mind in architecture, as was noted by Stavric and Marina (2011). One of these is the architectural constructive parametric design, and the other is the architectural conceptual parametric design. In architectural constructive parametric design, focus is made upon the forms, which are easier to produce in real life, and the work is carried out using pre-drawn 3D objects: BIM programs (such as Revit and ArchiCAD) are used for this purpose. In the architectural conceptual parametric design, the creation of complex forms, which are difficult to produce in reality, is focused on and generally the Rhino and Maya programs, which have script editors, are used (Stavric and Marina, 2011). The experimental work in this article has been made on architectural conceptual parametric design.

Kolarevic (2003) states that 'architects have always looked beyond the boundaries of their discipline, appropriating materials, methods and processes from other industries as needed'. Parametric operations which are based on a computer programming language, concern the modification of the declared values of constraints and parameters without transformation in the geometry or topology and the relations between them (Woodburry, 2010). This operation helps architects to generate a set of forms which are mostly complex in nature, curvilinear surfaces and non-Euclidean geometry that are difficult to manage via conventional methods (Burry, 2003; Lee et al., 2014). This type of complex form production with hand drawing or with an ordinary 3D modeling program is difficult since much effort and time are required. In addition, the lower levels of the model are required for each of the changes to be made in the main model; however, the parametric design program is itself able to make these changes, rather than it being necessary for the designer to do it (Burry, 1999; Jabi, 2013).

Since standardised forms with Euclidean geometry were easy to produce and the machines available were capable of creating many of them in a short period time, these forms emerged in many parts of the world following the industrial revolution. However, this progress brought a contrast approach that includes the use of avant-garde forms in architecture with non-Euclidean geometry. Today, such new types of fabrication tools as 3D printing and robotics have made the non-Euclidean geometries possible to produce, such that the demand for designing avant-garde forms has increased (Agirbas, 2015). Although the production of these forms has increased to the present day, some methods associated with the production of such form before the industrial revolution are also used. In the time before the computers were widely used in architecture, different experimental procedures were used in research on non-Euclidean geometry. For example, Gaudi (1852-1926), Isler (1926-2009), Otto (1925-2015) and Musmeci (1926-1981) carried out form-finding studies by examining self-formation processes in nature. These forms, which were found by making physical models, rather than drawings, were attempted to transfer to the architecture (Tedeschi, 2014). Pugnale (2014) goes further back in time, and states that the oldest form-finding method is 'the reverse hanging method' which is used to create shells, vaults and arches.

Today, it is obvious that types of computer software are employed directly in the designing process of non-Euclidean geometries. One approach to working with these types of geometries is to use various kinds of parametric architecture software as a tool which lets us to create a set of forms. However, there is no specific methodology available for their application to architecture and architectural education. Therefore, we have attempted to use metaphors in designing avant-garde forms with parametric architecture tools.

The Use of Metaphors in Architectural Design

Lakoff and Johnson (2003) claim that one of the aspects of imagination is seeing something in terms of another thing, and metaphorical thinking is understanding and experiencing one kind of thing in terms of another. Our perceptions can be differentiated by metaphors which alter our sense of reality. In other words, reality undergoes phases of metamorphosis through metaphors (Ricoeur, 1991; Schon, 1993; Lakoff, 1993). There is a constant use of metaphors in architectural design (Di Palma, 2006; Casakin, 2011; Goldschmidt and Sever, 2011; Caballero, 2013): thus, in the metamorphosis process of architectural design, the designer activates knowledge obtained previously, and in the light of this knowledge, establishes connections within the mind. In his late formulation of hermeneutics, Ricoeur (1988) explained this situation as being our negotiation between the *space of experience* and the *horizon of expectation*. Historical narratives uncover our *space of experience*, while fictional narratives relate to our *horizon of expectation* (Perez-Gomez, 1999). This process generally occurs via a holistic approach, in which the individual elements are created from the whole.

The use of metaphors in the architectural design process can be observed throughout history, and may vary across different periods of time. Dictums, technology, symbols, nature, biology and many other factors can be used as metaphors in the design process. For example, the dictum of the Modern Movement in architecture 'form follows function', (which means that the internal use of a building gives rise to the external appearance of the building), influenced a whole generation of architects (Colquhoun, 2002). As Casakin (2007) has noted, Frank Lloyd Wright is the best known architect who used this dictum as a metaphor in most of his works, e.g. the Robie House at Chicago, the Fricke House, the William Martin House, the Oscar Balch House, and the Unity Temple. He characterized his works with 'additive simple volumes interlocking with relative freedom to each other in accordance to functional needs'. In addition, Mies van der Rohe's memorable metaphor 'less is more' brought a minimalistic approach to architecture during that same period of time (Casakin, 2007).

For a long time, architects used nature as a source of inspiration, and incorporated natural forms as metaphors in their buildings. As Knippers and Speck (2012) noted, 'architects transferred the variety of natural shape and form directly into their work alternated with those of strict geometrical order'. For example, Buckminster Fuller used nature as a model for such inventions as the geodesic dome. Another example is the Notre-Dame du Haut Chapel building of Le Corbusier, which was built in 1954. Although the design of the chapel began with the idea of a crab, a viewer might interpret the building in terms of many other different forms, and there is no unique form that might be ascribed to it. This is the most important feature of a metaphor and it is this which differentiates it from an analogy. Similarly, we can see this in the Lyon-Satolas Station, which was designed by Calatrava (Tzonis and Lefaivre, 1995; Casakin, 2006), using the metaphor of a bird; in the Turning Torso building, which was designed by using the human body as a metaphor; in the Heinz-Galinski School building, designed by Zvi Hecker, using a sunflower as a metaphor (Oxman, 2002; Caballero, 2013); and in the Dancing House, designed by Frank Gehry, using the metaphor of dance.

In contemporary architecture, the working principles of nature are taken as metaphors for generative design practices. As noted by Janssen and others (2000), 'evolutionary programs use biological evolution in nature as a source of inspiration, rather than a phenomenon to be accurately modelled'. Generative design techniques (Singh and Gu, 2012), such as Genetic Algorithms (Holland, 1992) (inspired by the natural evolutionary process and often used for optimization to find the most appropriate solution), L-systems (Lindenmayer, 1968) (reflecting the characteristics of biological growth by generating fractal-like forms with self-similarity) and the Swarm Intelligence (Camazine, 1991; Bonabeau et al., 1999) agent-based model (Reynolds, 1987; Dorigo et.al., 2000; Jacob and Von Mammen, 2007) (based on the social or collective behaviours in nature) use the formations in nature as metaphors.

Methodological Procedures

As observed by Oxman (2008), the digital architectural design era changed the paper-based traditional architectural design education model and led to a search for new methodologies for design education. CAD (computer-aided design) models were an imitation of the paper-based design model in terms of principles, theories and methods. Today, however, new softwares are still being developed and participate directly in the designing process. We have therefore attempted to use these new softwares with a methodology that aims to use metaphors to advance the progress of parametric design.

Parametric design, which enables the creation of non-Euclidean geometric forms, is a subject much in demand for the instruction of architecture students. Therefore, the parametric design course was held at the architecture faculty of the university. It is useful to discuss the teaching methodology of this course, which is based on the use of metaphors in parametric design, where, despite limited time, the students were able to complete fine projects in a collaborative working environment.

The present research work began with the question: "How can effective teaching of parametric design tools be done in a limited period of time?" Since the best way of learning about the computer aided design tools is to actually undertake application-oriented work, it was found appropriate to carry out an application task within the course with a chosen methodology. The other research question in this study was, "Is it possible to use metaphor in a methodological way within the system of parametric design education, which can guide the student in the design process?" The course on teaching the use of parametric design tools in the architecture department is in the “elective” category. The elective course occupies 2 hours a week during a 14 week long semester (this work was done in Spring 2017). This elective course is open to both students in the later period of their architectural education, or to architecture students in their earlier educational phase. However, in the present study, which involved 17 students, most of the students were in the 3rd or 4th years of their undergraduate education. During this study, one to one discussions with students about their designs were done for each course. The conclusions of this study are based on inferences about the process of using computer-aided design tools by students, and about the process of script development, and also inferences about the effect of metaphor on the design process, which were drawn from the observations and discussions in one to one meetings by the author. In addition, inferences about the use of metaphor in parametric design education were drawn from the author's evaluation of the students` final design products in the context of a parametric design-metaphor.

In contemporary architecture, architects are increasingly adopting non-Euclidean geometry as a means to achieve forms of differing type. Hence, the boundaries of the technology are defined, and new developments are enabled, such that architects are able to satisfy their aesthetic understanding, enforce the limits in production, and experience the opportunity to work with different materials (Kolarevic, 2003). However, although the computer programs, which allow us to create non-Euclidean geometric forms, are very effective, the creation of such forms with a high aesthetic value is very difficult unless specific restrictive elements are present, during the form-finding process. The creation of these aesthetic forms is normally particularly difficult for architecture students. For those form-finding studies, which do not have a particular restriction or do not advance via a specific methodological framework, the results are generally achieved in the form of a gum. Such gum type forms are those which lack aesthetic satisfaction due to an absence of certain characteristics. Therefore, the identification of metaphor as a restrictive element in form-finding studies in this course, helps students to redirect their attention to production of the forms.

In those undergraduate elective courses which employ computer-aided design, the biggest problem that the students generally find is the practical implementation of classroom theory to an actual project. This is due to the fact that the classroom teaching is done outside of the architectural design studios, and there is little time to learn how to integrate the two aspects. However, the most efficient way of learning in architecture is to implement a project on the basis of which was learned in class. In this way, students learn to consolidate their knowledge from the course and how to use this in the architectural design process. Therefore, in the limited hours of the elective course given by the author, an experimental study on the production of the projects was carried out. In this way, the students were able to experience the coding in parametric design and all the processes, beginning with a virtual model, up to the digital fabrication stage. This systematic progression was achieved by means of the theoretical framework of the use of metaphor in architectural design.

Although most of the students were familiar with the use of some softwares before the course, they had no experience of Rhinoceros and Grasshopper which were the main softwares that were used in the course. The basics of Rhinoceros, which was used as the base for parametric design platform with Grasshopper, was explained in a series of lectures. Since most of the students had previously experienced other 3D modeling environments like SketchUp or 3DsMax, it was easy for them to assimilate the basics of Rhinoceros.

Afterwards, we covered the basics of parametric design and the use of Grasshopper. The students who had no experience with this type of visual programming language, were naturally anxious. Lectures on Grasshopper scripts were given, and despite the fact that the students were initially concerned about the new working environment, they began to enjoy using the program when they saw the outcomes of the scripts. For the work, which the students will carry out within the scope of this lesson, a base script was written in the class by the instructor, who explained the details of the operation of the script to them. In this script, an ellipse is created and this is arrayed on the Z-axis. This ellipse set, formed along the Z-axis, is rotated according to the range parameter, to determine the proportional rotation of each ellipse in the ellipse set. Later, the Loft command is added to the script, which creates a surface that surrounds the ellipse set, which is rotated. The resulting surface is transformed into 3 dimensions, and divided both vertically and horizontally. Finally, the Morph command, which permits the assignment of an object according to each unit in the divided surface, is added to the script. Hence, an object with any form produced in Rhino can easily be added to these units. With the script, the added object can be shaped according to the different forms of the units in the created surface (Figure 1). After the students had performed the operation of this script, they began to play with the script by changing sliders and adding different components. At this point, they were actually in the form-finding phase and started to make digital sketches.

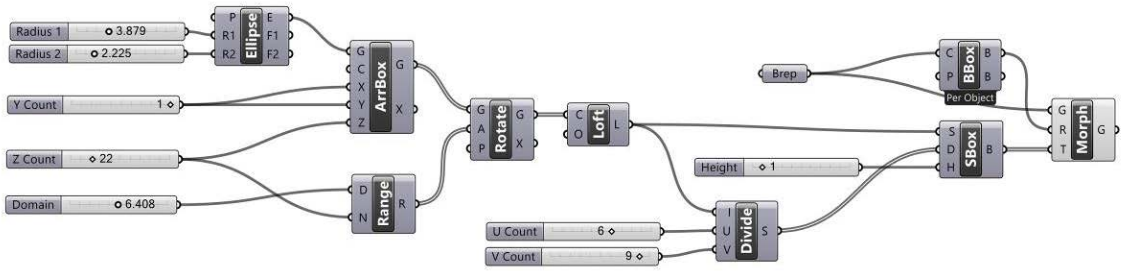


Figure 4. A script developed for the students to use as a base model in their designs

Meanwhile, presentations were made to the students in connection with metaphors, which were chosen to relate to their use in architecture. Projects designed by architects such as Frank Gehry, Santiago Calatrava and Zvi Hecker were shown to students, who were then asked to interpret them. The students likened the projects to various different objects, and by means of these different interpretations, the use of metaphor was focused on as the initial step from which to achieve different designs rather than to determine the exact forms.

The students determined the particular design issues for their own designs. After they decided what to design, they were asked to find a metaphor for their form of design, and continue to design on an architectural scale. At this stage, the use of metaphors in the designing process had been started. This process allows students to manage the form-finding progress more efficiently. The methodology worked quite well and the students continued to work in an interactive environment.

In order for them to undertake the design process, the students were informed in advance about the necessity of them knowing details of the digital fabrication machines to be used during the digital fabrication. This enabled the students to make 3D models that were compatible with the 3D printer. As Kolarevic (2008) said: ‘knowing the production capabilities and availability of particular digitally-driven fabrication equipment enables designers to design specifically for the capabilities of those machines.’ The students were also told how long it would take to achieve the digital fabrication, thus enabling them to make adequate time management regarding digital fabrication process.

Results

Some of the products made by the students during the course are shown in Figures 2-7. In Figure 2, the student took a snake as a metaphor which helped him in the form-finding process of his design, while thinking and observing the morphology, skin and positioning of the creature according to its environment. In Figure 3, the student took the body movements of Sufi-whirling (which is a physically active meditation method), as a metaphor for his minaret design, and thought about the shapes that the body movements make. He also added an octagonal star which is known as a Seljuk star, as a symbolic metaphor to his minaret design. In Figure 4, the student considered flames as a metaphor for her design. After modeling the form of flames, she started to aggregate the prototypes together in order to create a multi-function port. In Figure 5, the student took Chidori toys as a metaphor, and developed the idea on an architectural scale using the parametric design tools. He created non-standard spaces, as inspired by Chidori toys, which are actually in Euclidean geometries. The student took the DNA helix as a metaphor in order to create a bridge, as shown in Figure 6, and another student took erythrocyte as a metaphor in order to create a façade of a skyscraper as shown in Figure 7.

The students were at liberty to design any type of building and to use any metaphors for their forms of designs. Some of them used a metaphor for each unit of the gridally divided surface (Figure 4, Figure 5,Figure 7), while some of them used metaphors for the geometry of the entire form (Figure 2, Figure 3, Figure 4, Figure 5,Figure 6). One of the students used a particular metaphor for the general form of his design and a related but different metaphor for each unit of the surfaces (Figure 3). As can be seen from the figures, the metaphors that they selected were inspiring sources for the designs rather than just copying the forms of them.

In the form-finding process, the relationship between the configurations of the script and the created forms began to be understood more clearly. Hence, the students gradually started to connect what they saw on the screen, with the related parts in the script that they wished to refine, and therefore either changed some of the parameters in the script, or added new components. For example, in Figure 2, the student wanted to fit the form onto a curved landscape in a harmonious manner. Accordingly, he wanted to use a 2D surface instead of the cylindrical surface created from the ellipses in the first script. For this, he retained the partitioning part of the first script with its Morph components, but instead of a cylindrical surface being created by the ellipses, he generated a new surface with the help of the curves. Thus, by refining the script he could experience parametric design thinking (Oxman, 2017). Similarly, in Figures 5 and 9, the students wanted to duplicate a holistic single object that could be produced by the first script, and to achieve this, they could make copy-based additions to the script.

The designer advances his design using conceptualization, modification, refinement (Cross, 1982; Cross, 2006; Cross, 2011), or with observation and visual documentation (Schon, 1983, Schon, 1987, Schon, 1988), during the phase dominated by the use of paper-based tools. However, the cognitive model of design thinking using iterative processes became non-applicable in the period that was dominated by the first use of CAD tools, because they did not have a re-editing feature (Oxman, 2017). Currently, with the use of non-algorithmic modeling tools, particularly, the example of digital sketch is achieved in a given period of time in the design process. However, after a certain period of time has been occupied by the design process, re-editing becomes very difficult and thus design thinking related to the iterative process becomes impossible. Therefore, such modeling tools are now generally used only for presentation purposes. On the other hand, algorithmic modeling tools are seen to be included increasingly in design processes. Thus, as this study shows, by means of parametric design models, the designer can provide reconfiguration, re-editing and modification according to his individual mode of thinking (Oxman, 2017). Hence, there appears to be a similarity between the first cognitive model of design thinking (Cross, 1982; Schon, 1983), which emerged during the use of paper-based tools, and the design thinking of the period that is characterized by the use of algorithmic-based digital tools.

During the design for digital fabrication, the students were careful to prepare their 3D models in a suitable form for 3D printing (watertight). However, the tissue of the forms, which some of the students produced, became quite complex, and it was found simpler to neglect the tissue type in order to avoid spending a long time over making it compatible with a 3D printing (Figure 8). Such knowledge obtained during the early years of their undergraduate education will urge the students to consider the relationship of their complex forms with 3D print in the earlier design-stages for future projects. Other students attempted to make the 3D print in different pieces for the digital fabrication stage (Figure 9), according to the scale of the print, which could be accommodated by the 3D printer. Accordingly, the students were able to learn to develop their design in with the context of the capacity of the machine, which they used to create the actual, final object.

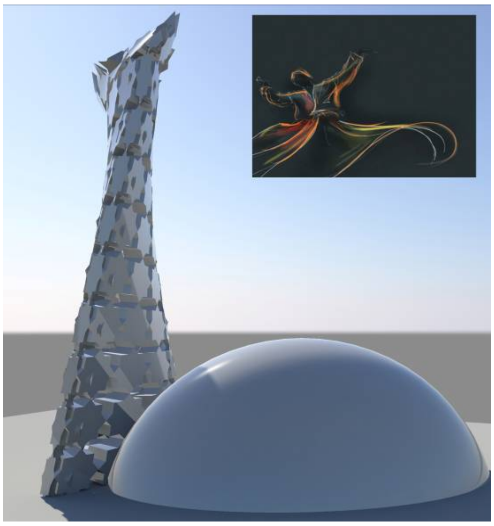
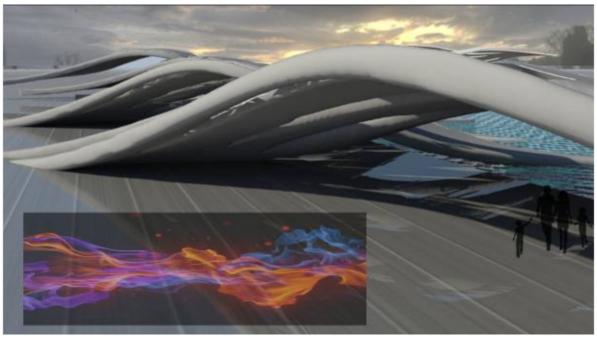


Figure 5. Use of nature/biology as a metaphor (Work of a student)

Figure 6. Use of a symbol as a metaphor (Work of a student)



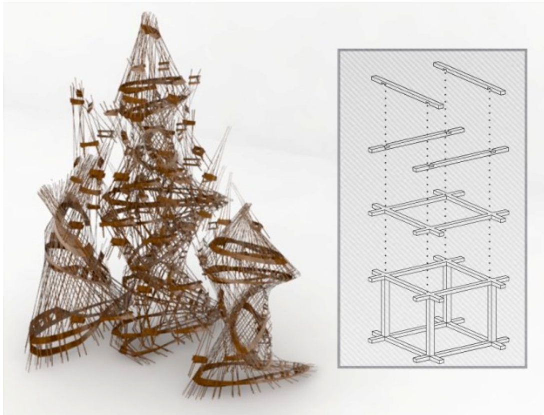
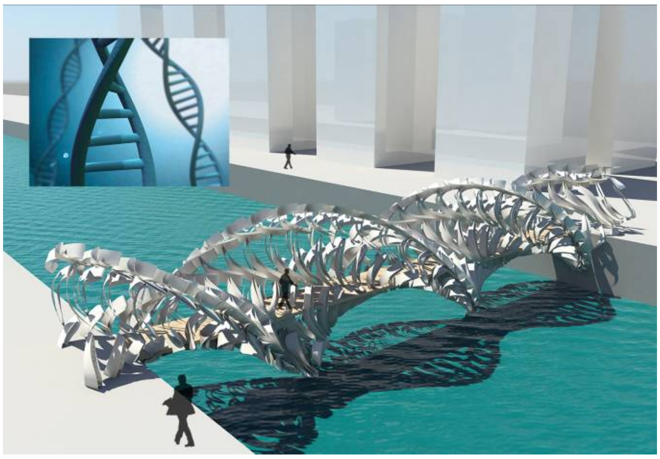


Figure 7. Use of nature as a metaphor (Work of a student)

Figure 8. Use of a symbol as a metaphor (Work of a student)



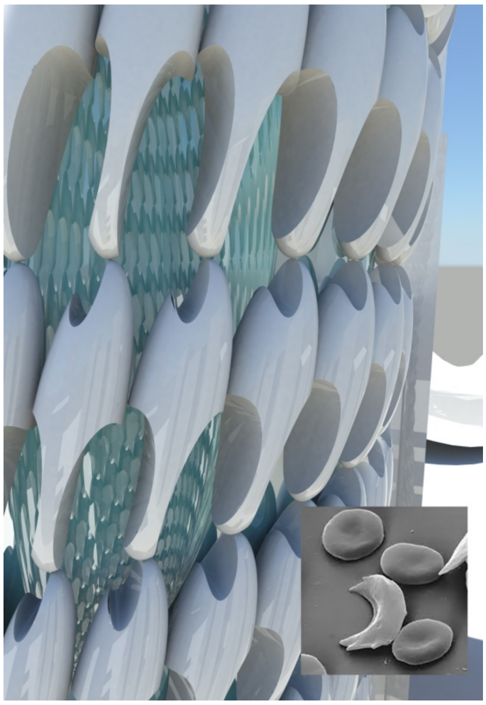


Figure 9. Use of nature/biology as a metaphor (Work of a student)

Figure 10. Use of nature/biology as a metaphor (Work of a student)

Figure 11. The work of a student and its 3D print.

Figure 12. The work of a student and its 3D print.

Conclusion

The advent of the digital era changed the paper-based tradition in architecture and design, and accordingly, the nature of design education has also changed, with the use of many computer-aided design tools being included in the design process. Parametric design tools, which are based on visual programming languages, recently became popular, and are now a feature of many undergraduate education programs. Hence, the use of these tools has increasingly influenced the design process. Therefore, although the present case study was made specifically in the field of architecture, its inferences on both the design process and design thinking, as related to the use of parametric design tools, will also be of interest to other fields of design.

The students found metaphors that can lead to the development of their designs on an architectural scale. In this way (by placing the course under the metaphor theoretical framework), the students developed their projects at the form-finding stage, using certain constraints and at the same time, were able to learned the visual programming language, which was the purpose of this elective course. Parametric design provided them with many forming options that they could choose one from; however, the use of metaphor methodology led them to limit the parameters. Since they focused on the shape or the concept of their metaphors, they started to neglect some of the parameters that are offered by parametric design tools. Also, the use of metaphors in the parametric architectural design process allowed them to control avant-garde forms easily since the forms have no limitations, in contrast to those with Euclidean geometries.

The students learned versatile thinking and how to use different tools in combination, since they experienced simultaneously the use of codes, to prepare 3D models that are compatible with digital fabrication, material based thinking and how to undertake effective time management. These are all important aspects of the use of the technology that is widely used in contemporary architecture. It is this rapidly developing technology which offers many different alternatives to architects, who may choose it for use in accordance with the intended design (such as materials, machinery, software) and to use selected different tools together. Therefore, it is important that students are able to experience the benefits of using a combination of different tools during their education, prior to becoming practicing professional architects.

The deductive process was followed so that the students could obtain a clear understanding of those circumstances where parametric design tools are useful and of the relationship between object and script configurations, and therefore of the cognitive model of design thinking for parametric design. As a result of the experimental study, the students were observed to understand the logic behind the parametric design tool. Furthermore, those students who wanted to make some refinements to a form basis, could modify the form in the direction indicated by the relation between the script configurations and the form of the object, which shows that they experienced the process of parametric design thinking.

At the university, traditional architectural design learning (which mostly depends on the Modern Movement in architecture), leads bachelor of architecture students to create bubble diagrams that shape the buildings according to their functional needs. In other words, we may describe it as a 'form follows function' based methodology, which mostly depends on an inductive reasoning process of form generation. Contrarily, in this course, the students were free to design in a bottom-up mode, which will influence their future project work. They started to consider both form and function in their designs by making reiterative movements within the architectural design process. This new cognition is partly influenced by the 3D modeling environment that students designed directly via a 3D image, rather than designing within a 2D environment, such as a plan or section. We may therefore conclude that courses with different teaching methodologies can allow architecture students to benefit from both processes of inductive and deductive reasoning.

The above described teaching methodology permits the students to create their own designs rapidly. The time to create their designs is further reduced by the fact that the methodology limits some parameters that are offered by the programming language. Although this methodology seems beneficial for elective courses, since it allows students to learn the basics of computer programming languages and also to create forms simultaneously, it may not be beneficial for longer term design projects since the students need to consider additional parameters to make appropriate progress. However, for form-finding processes on a short timescale, the use of metaphors in parametric design can be useful and can be considered as an additional parameter to the script that limits forming options.

The study, which was carried out as part of the content of this elective course, was limited to the issue of form-finding. However, other parameters such as context, function, intention, program and structure, which are within the scope of the architectural design studio course, can be added to the content of this applied method, such that later experimental studies can be made, and the results of these can be evaluated.

References

Agirbas, A. (2015) The Use of Digital Fabrication as a Sketching Tool in Architectural Design Process: A Case Study, in B. Martens et al. [ed] Proceedings of the 33rd eCAADe (Education and Research in Computer Aided Architectural Design in Europe) International Conference, Vienna, Austria, September 16-18, pp. 319-324.

Bonabeau, E., Dorigo, M. & Theraulaz, G. (1999) *Swarm intelligence: From natural to artificial systems*. New York, NY: Oxford University Press.

Burry, M. (1999) Paramorph: Anti-accident methodologies, in S. Perella. [ed] *Architectural Design: Hypersurface Architecture II*. Chichester: Wiley, pp. 78-83.

Burry, M. (2003) Between Intuition and Process: Parametric Design and Rapid Prototyping, in B. Kolarevic [ed] Architecture in the Digital Age: Design and Manufacturing. London: Spon Press, pp. 148-162.

Caballero, R. (2013) The Role of Metaphor in Architects' Negotiation and (Re)Construction of Knowledge Across Genres, *Metaphor and Symbol*, 28(1), 3-21.

Camazine, S. (1991) Self-organizing pattern-formation on the combs of honeybee colonies, *Behavioral Ecology and Sociobiology*, 28(1), 61–76.

Casakin, H.P. (2006) Assessing the use of metaphors in the design process, *Environment and Planning B: Planning and Design*, 33(2), 253 – 268.

Casakin, H.P. (2007) Metaphors in Design Problem Solving: Implications for Creativity, International Journal of Design, 1(2), 21-33.

Casakin, H. (2011) Metaphorical reasoning and design expertise: A perspective for design education, *Journal of Learning Design*, 4(2), 29–38.

Colquhoun, A. (2002) Modern architecture. Oxford and New York: Oxford University Press.

Cross, N. (1982) Designerly ways of knowing, *Design Studies*, 3(4), 221-227.

Cross, N. (2006) *Designerly Ways of Knowing*. London: Springer.

Cross, N. (2011) *Design Thinking*. Oxford-New York: Bloomsbury Publishing.

Di Palma, V. (2006) Architecture and the organic metaphor, *The Journal of Architecture*, 11(4), 385–390.

Dorigo, M., Bonabeau, E. & Theraulaz, G. (2000) Ant algorithms and stigmergy, *Future Generation Computer Systems*, 16(8), 851–871.

Goldschmidt G. & Sever A.L. (2011) Inspiring design ideas with texts, *Design Studies*, 32(2), 139–155.

Holland, J.H. (1992) *Adaptation in Natural and Artificial Systems: An Introductory Analysis with Applications to Biology, Control, and Artificial Intelligence*. Cambridge, MA: The MIT Press.

Jabi, W. (2013) *Parametric Design For Architecture*. London: Laurence King Publishing.

Jacob, C. & Von Mammen, S. (2007) Swarm Grammars: Growing Dynamic Structures in 3D Agent Spaces, *Digital Creativity*, 1(18), 54-64.

Janssen, P., Frazer, J. & Ming-xi, T. (2000) Evolutionary Design Systems: a conceptual framework for the creation of generative processes, in *H. Timmermans [ed] Proceedings of the 5th International Conference on Design Decision Support Systems in Architecture and Urban Planning*, *Nijkerk, The Netherlands, August 22-25, pp. 190-200.*

Knippers, J. & Speck, T. (2012) Design and construction principles in nature and architecture, Bioinspiration & Biomimetics, 7(1), 1-10.

Kolarevic, B. (2003) Architecture in the Digital Age: Design and Manufacturing. London: Spon Press.

Kolarevic, B. (2008) The (Risky) Craft of Digital Making, in B. Kolarevic & K. Klinger [eds] Manufacturing Material Effects: Rethinking Design and Making in Architecture. New York: Routledge, pp. 119-128.

Lakoff, G. (1993) The contemporary theory of metaphor, in A. Ortony [ed] *Metaphor and Thought.* Cambridge: Cambridge University Press, pp. 202 -251.

Lakoff, G. & Johnson, M. (2003) Metaphors We Live By. Chicago: University of Chicago Press.

Lee, J.H., Gu, N., Jupp, J. & Sherratt, S. (2014) Evaluating Creativity in Parametric Design Processes and Products: A Pilot Study, in J.S. Gero [ed] *Design Computing and Cognition'12*. Springer, Dordrecht, pp. 165-183.

Lindenmayer, A. (1968) Mathematical models for cellular interaction in development I. Filaments with one-sided inputs, *Journal of Theoretical Biology*, 18, 280-289.

Oxman, R. (2002) The thinking eye: Visual re-cognition in design emergence, *Design Studies*, 23(2),135–164.

Oxman, R. (2008) Digital architecture as a challenge for design pedagogy: theory, knowledge, models and medium, Design Studies, 29(2), 99-120.

Oxman, R. (2017) Thinking difference: Theories and models of parametric design thinking, *Design Studies*, 52, 4-39.

Perez-Gomez, A. (1999) Hermeneutics as Discourse in Design, *Design Issues,*15(2), 71.

Pugnale, A. (2014) Digital Form-Finding, in A. Tedeschi [ed] *AAD_Algorithms-Aided Design: Parametric Strategies Using Grasshopper*. Brienza: Le Penseur Publisher, pp. 353-359.

Reynolds, C.W. (1987) Flocks, Herds, and Schools: A Distributed Behavioral Model, *Computer Graphics*, 21(4), 25-34.

Ricoeur, P. (1991) The function of Fiction in Shaping Reality, in M.J. Valdes [ed] A Ricoeur reader: Reflection and imagination. Toronto: University of Toronto Press, pp. 117-136.

Ricoeur, P. (1988) *Time and Narrative*. Chicago IL: The University of Chicago Press.

Schon, D.A. (1993) Generative Metaphor: a perspective on problem-setting in social policy, in A. Ortony [ed] *Metaphor and Thought*. Cambridge: Cambridge University Press, pp. 137 – 163.

Schon, D. A. (1983) *The Reflective Practitioner: How Professionals Think in Action*. New York: Basic Books.

Schon, D. A. (1987) *Educating the Reflective Practitioner: Towards a New Design for Teaching and Learning in the Professions*. San Francisco: Jossey-Bass.

Schon, D. A. (1988) Designing: Rules, types and worlds, *Design Studies*, 9, 181-190.

Singh, V. & Gu, N. (2012) Towards an integrated generative design framework, *Design studies*, 33(2), 185-207.

Stavric, M. & Marina, O. (2011) Parametric Modeling for Advanced Architecture, *International Journal of Applied Mathematics and Informatics*, 5(1), 9-16.

Tedeschi, A. (2014) *AAD_Algorithms-Aided Design: Parametric Strategies Using Grasshopper*. Brienza: Le Penseur Publisher.

Tzonis, A. & Lefaivre, L. (1995) *Movement, Structure and the Work of Santiago Calatrava*. Basel: Birkhauser.

Woodbury, R. (2010) Elements of Parametric Design. London and New York: Routledge.

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23.1

Augmented Reality, Virtual Reality and their effect on learning style in the creative design process

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Abstract

Research has shown that user characteristics such as preference for using an interface can result in effective use of the interface. Research has also suggested that there is a relationship between learner preference and creativity. This study uses the VARK learning styles inventory to assess students learning style then explores how this learning preference affect the use of Augmented Reality (AR) and Virtual Reality (VR) in the creative design process.

Key words

augmented Reality, Virtual Reality, Learning styles, Design education, Creativity.

Introduction

Individuals use interfaces in different ways for different purposes. Research has shown that user characteristics such as preference for using an interface can result in effective use of the interface. Factors such as cognitive style, gender, and preference have been shown to impact creativity and the ideation process (Baer, 1997; Baer & Kaufman, 2008; Lubart, 1999; Pearsall, Ellis, & Evans, 2008; Shalley, Zhou, & Oldham, 2004; Wolfradt & Pretz, 2001). Furthermore, there is a relationship between learner preference and creativity (Atkinson, 2004; Eishani, Saa'd, & Nami, 2014; Friedel & Rudd, 2006; Kassim, 2013; Ogot & Okudan, 2007; Tsai & Shirley, 2013). The purpose of this study is to explore how user characteristics (i.e. learner preferences) affect the use of Augmented Reality (AR) and Virtual Reality (VR) in the creative design process. While VR can be interpreted as immersive three-dimensional computer-generated environments (Bryson, 1995), AR can be conceptualized as overlaying virtual objects over the physical environment (Fischer et al., 2006). Researchers have investigated how AR and VR can be used in design and design education, but there is a gap in knowledge about how these interfaces affect the cognitive process of designing.
The VARK Learning Styles inventory was used to measure learner preferences for visual, auditory, read/write, and kinaesthetic learning styles. The VARK is considered to be a valid learner preferences tool and it has been used by many researchers (Bell, Koch, & Green, 2014; Drago, & Wagner, 2004; Lau, Yuen, & Chan, 2015). It was used in this study because it focuses on kinaesthetic and visual learning styles, which relate to the characteristics of the interfaces that are investigated in this study. The rationale in this study was that learners with a preference for kinaesthetic learning will prefer to use an interface that provides more

tactility, while those who have a preference for visual learning will prefer to use an interface that provides more visual cues.

Learning styles are thought of as a user's preference for using a certain modality as a means to learn. The main hypothesis of the study stems from the fact that the learner preference correlates to the acceptance of that particular technology, thereby affecting the creative design process through intrinsic motivation (see Figure 1).

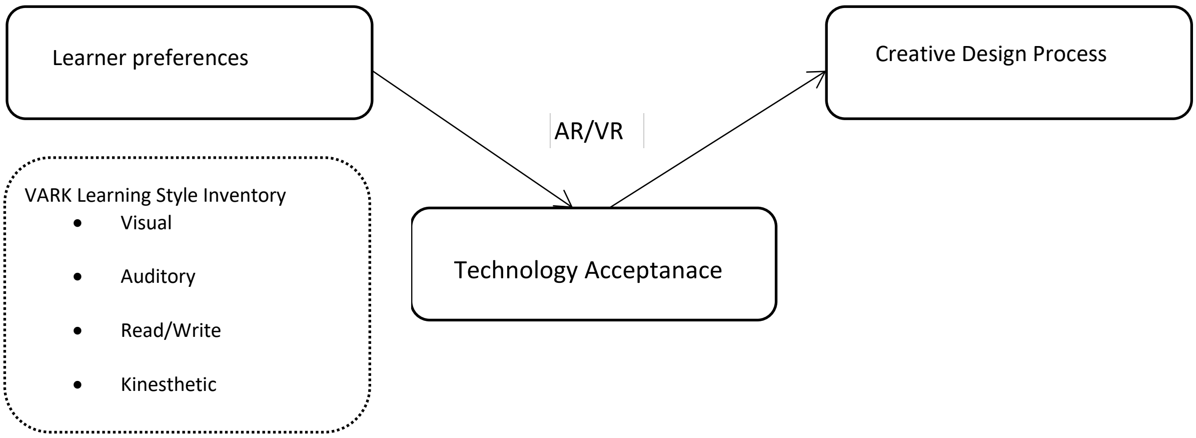


Figure 1. Effect of learner preferences on using AR and VR in the creative design process.

Virtual Reality (VR) and Augmented Reality (AR)

VR has been extensively used in educational environments. As AR technology is becoming more accessible, it is being more often adapted for mainstream use. While VR can generally be interpreted as an immersive three-dimensional computer-generated environment, AR can be thought of as overlaying of the virtual over the physical environment.

VR is a simulated three-dimensional environment which either emulates the real world or acts as an imaginary world. Even though the majority of virtual environments cater to the visual sense, virtual environments can cater to the auditory, haptic, olfactory, and even the taste sense. VR is commonly used as an entertainment, education, and research tool. It offers a wide variety of options and opportunities in conducting research, especially in human behaviour research, since virtual environments can be controlled according to the need of the researcher.

AR has been defined as a variation of VR (Azuma, 1997). While VR completely immerses the user inside a computer-generated environment where the user cannot relate to the physical environment, AR allows the overlaying of virtual elements onto the physical environment. AR can be considered a hybrid of virtual and physical environments and therefore supplements reality rather than replacing it. Given the similarities and overlapping of certain characteristics between these two interfaces (AR and VR), there is a critical need to identify advantages or disadvantages of one over the other for its use in a specific domain. AR is an interface that offers tangible interaction (Ishii, 2007) and is often referred to as tangible user interface (TUI). There for the tangible nature of AR might appeal to kinaesthetic users as compared to the visual nature of VR, which might appeal more to the visual learners.

Even though AR has existed for several decades, there is a gap in the knowledge about how human factors affect the use of AR (Huang, Alem, & Livingston, 2012). Better understanding of user experience factors in AR environments is important for a number of reasons. With the emergence of new hardware that has the capability of supporting AR applications, interest in how to use this technology efficiently has been increasing. Such studies are only currently becoming feasible because of the recent maturation of the technology. Extensive studies of this type will allow the development of specific and general design and usage guidelines for AR technology not only in design education and design practice but in other fields of study as well. Moreover, understanding human perception of AR will accelerate the introduction of such technologies into mainstream use beyond the current novelty value of AR.

Effects of User Characteristics on the Design Process

Digital interfaces affect the design process in a number of ways, such as the way the individual use it, the familiarity with the tools and the intrinsic qualities of the tool. It is important to understand how these interfaces affect the design process and thereby the people using them. The purpose of this study is to explore digital interfaces and user preferences for learning.

Research on using digital media in design education has for the most part focused on the development of the technology. Whatever user evaluation has been done has focused on technical aspects rather than using a human-centred approach (Gab bard & Swan, 2008). Nevertheless, both system and user performance measurements are important aspects for AR because the technology coordinates the physical environment and the computer-generated overlaid environment (Grier et al., 2012).

In his 10 books on architecture, Vitruvius stated that an architect should be a good writer, a skilful draftsman, versed in geometry and optics, expert at figures, acquainted with history, informed on the principles of natural and moral philosophy, somewhat of a musician, not ignorant of the law and of physics, nor of the motions, laws, and relations to each other, of the heavenly bodies (as cited in D'Souza, 2009, p. 173). Apart from these basic technical skills, an architect is assumed to have or acquire imagination and be creative and must gain artistic and intellectual abilities as well (Potur & Barkul, 2007). Isham (1997, p. 2) stated, "The ability to concisely communicate a highly complex and creative design solution has at its creative core visualization skills (internal imaging) that allow designers to mentally create, manipulate and communicate solutions effectively."

These different characteristics that make a designer may depend on the designer's innate skills and intelligences as well as the learning method. Thurstone (1938) described intelligence as a combination of factors such as associative memory, number facility, perceptual speed, reasoning, spatial visualization, verbal comprehension, and word fluency. He further identified three factors of spatial ability, mental rotation, spatial visualization, and spatial perception. D'Souza (2006) stated that designers use the seven types of intelligences which Gardener (1983) discusses – logical, kinaesthetic, spatial, interpersonal, intrapersonal, verbal, and musical intelligence – and suggested the addition of graphical, suprapersonal, assimilative, and visual intelligences to the types of intelligences so that the framework for design intelligence is more comprehensive.

According to Gardner's multiple intelligences theory, individuals have a distinctive capacity to succeed in a particular field, and the method of educating these individuals should foster these intelligences. The idea of learning styles suggests that individuals have a particular way of learning that works best for them. For example, some individuals learn more easily from visual activities and some learn more easily from hands-on activities. Educators should identify the learning style best suited for the student.

Understanding the learner preferences of the individual is important when selecting the instructional medium. In this study, emphasis is on learner preference instead of intelligences because this study focuses on the modality through which information is provided to the students (i.e., through the AR or VR interface).

Learning Styles

Researchers have attempted to identify how individuals learn and have provided a number of categorizations. The term "learning styles" was first used in an article by Thelen in 1954, and thereafter has been defined by many. Ausubel, Novak, and Hanesian (1968) defined it as "self-consistent, enduring individual differences in cognitive organization and functioning" (p. 203), while Keefe (1979) defined it as "cognitive, affective, and physiological traits that serve as relatively stable indicators of how learners perceive, interact with, and respond to the learning environment" (p. 2). A general definition of learning styles was provided by James and Gardner (1995) as the different patterns of how individuals learn.

A number of researchers have presented theoretical frameworks that explain these learning styles. Curry's (1983) onion model explores different learning style theoretical frameworks and provides four main categories: personality learning theories, information processing theories, social learning theories, and multidimensional and instructional theories.

According to the onion model, some learning theories focus on the personality of the individual (such as the Myers-Briggs indicator), information processing theories describe how individuals perceive and process learning activities. Kolb's (1984) model of information processing is an example of this type of theory. Social learning theories describe an individual's interaction with the environment. The fourth type attempts a more holistic view of learning through analysing multiple dimensions. In his multiple intelligence theory, Gardner described several dimensions of learning, such as inter personal, intra personal, visual-spatial, bodily-kinaesthetic, linguistic, and logical (Gardner, 1983).

While many of these theories propose using learning styles as a mechanism to better meld instructional modalities to cater to the individual, the rationale in identifying learning styles in this study is to understand the user preference for digital interfaces and the efficient use of that digital interface in the creative design process. Dunn (1993) stated that

> if individuals have significantly different learning styles, as they appear to have, is it not unprofessional, irresponsible, and immoral to teach all

> students the same lesson in the same way without identifying their unique strengths and then providing responsive instruction? (p. 30)

Therefore, the logical question that remains is not whether educators should instruct students in different ways but which methods are best for which students.

Learning Styles in Design Education

Learning styles that are applicable to design are defined by the way designers observe and solve design problems. Design educators have explored design students' learner preferences and styles by observing learner preferences of design students (Demirbas & Demirkan, 2003; Kvan & Jia, 2005). Newland, Powell, and Creed (1987) identified four types of design learners by using Kolb's learner styles as a starting ground. Durling, Cross, and Johnson (1996) observed cognitive styles using the Myers-Briggs type indicator (Briggs, 1976) to identify the connection between teaching and learning in design schools.

Students of different disciplines have shown preferences for a certain type of learning style. For example, using the VARK questionnaire, Lujan and DiCarlo (2006) found that medical students prefer multiple learning styles. Felder and Silverman (1988) stated that the learning styles of most engineering students are mismatched with teaching styles of most engineering professors and recommended that professors use different methods to facilitate the learner preference of the students. The learner preference of students from a certain discipline may be similar for a number of reasons, such as shared interests or similar aptitude. In design education, students tend to be more visual and to enjoy working with physical objects such as building prototypes. These preferences and aptitudes may predispose them to a certain learner preference.

Researchers have stated that the most important facet of design and design education is self-reflection, in which a designer would revisit and reflect on the design decisions that have been made (Newland, Powell, & Creed, 1987). Trial and error problem solving encourages and facilitates this type of self-reflective design ideation in enhancing the creative design process (Harnad, 2006). The fact that trial and error type of problem solving plays a major role in a design students' academic career might influence their learner preference as well.

Creativity, Motivation, and Acceptance

Motivation is generally understood as a personal drive to accomplish. Motivation can be intrinsic or extrinsic. Intrinsic motivation is defined as doing something for one's own satisfaction (Amabile & Gryskiewicz, 1987) and extrinsic motivation is defined as "the motivation to work on something primarily because it is a means to an end" (Amabile, 1987, p. 224).

Researchers have studied the connection between intrinsic motivation and creativity (Amabile, 1985; Collins & Amabile, 1999; Hennessey, & Amabile, 1998; Koestner, Ryan, Bernieri, & Holt, 1984) as well as motivation and creativity in the context of design (Casakin & Kreitler, 2010; Kreitler, & Casakin, 2009) and found that when motivation is less, creative output decreases (Collins & Amabile, 1999). Runco (2005, p. 609) stated that "creative potential is not fulfilled unless the individual is motivated to do so, and creative solutions are not found unless the individual is motivated to apply his or her skills."

Research has shown that extrinsic motivation for using assistive technology is captured by the PU construct in the TAM (Davis, 1989; Venkatesh & Davis 2000; Venkatesh & Speier, 2000). Furthermore, Venkatesh, (2000) stated that intrinsic motivation is related to PEU. Because technology acceptance is affected by perceived ease of use and perceived ease of use is affected by intrinsic motivation, intrinsic motivation would appear to affect technology acceptance (see Figure 2).

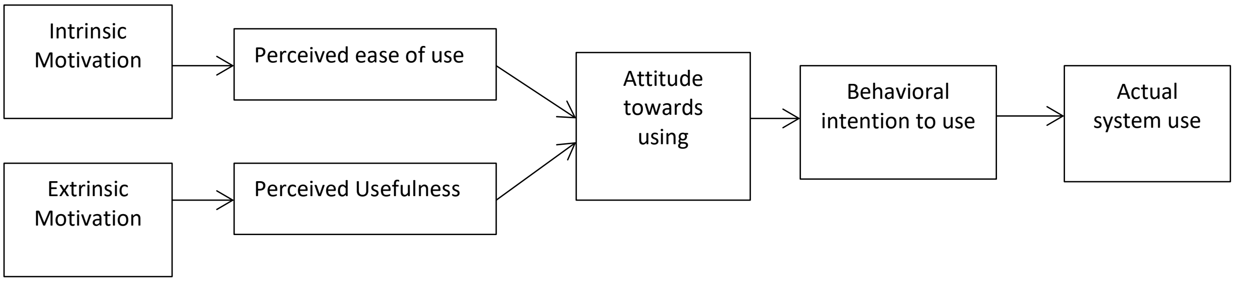


Figure 2. Effect of motivation on the technology acceptance model (TAM).

Perceived ease of use is a predictor of intrinsic motivation and intrinsic motivation enhances creativity. Through this link I examine whether perceived ease of use is related to creativity. Anasol, Ferreyra-Olivares and Alejandra (2013) proposed that the learning experience of kinaesthetic learners could be enhanced through the tangibility of user interfaces. They further stated that virtual environments can be used as extensions of traditional physical classrooms, motivating visual or aural learners. Therefore, they suggest that user preference would affect the use of VR and AR interfaces in design and thereby affect the creative design process (see Figure 3).

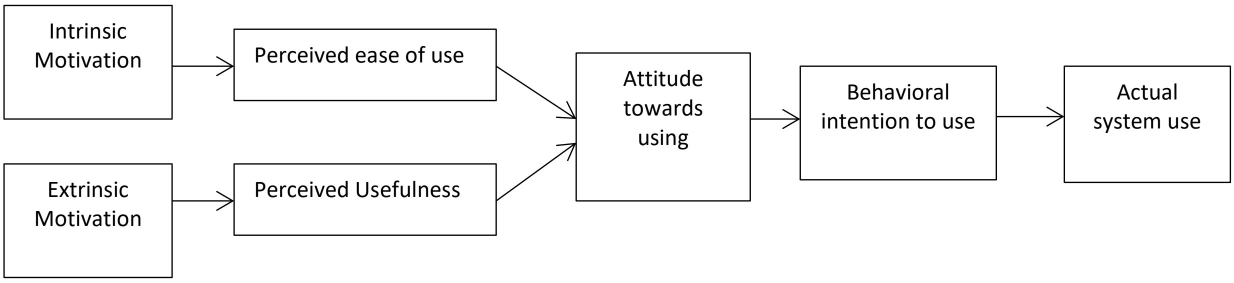


Figure 3. Effect of learner preference through digital modalities.

Measuring Learning Styles: VARK Learning Styles Inventory

The VAK (visual, auditory, kinaesthetic) and VARK (visual, aural, reading and writing, kinaesthetic) learning style inventories have been used in many studies (Bell, Koch, & Green, 2014; Drago, & Wagner, 2004; Lau, Yuen, & Chan, 2015; Marcy, 2001; Wehrwein, Lujan, & DiCarlo, 2007). Fleming (2001; Fleming & Mills, 1992) attempted to establish perceptual modes as a measurable construct through the VARK inventory, which focuses on the individual preferences of using different perceptive modalities in obtaining and retaining information efficiently.

Aural learners prefer receiving information through discussions, seminars, lectures, and conversations. Visual learners obtain information efficiently through pictures and other visual means such as charts, graphs, and other symbolic devices instead of words. Learners who prefer obtaining information through text are identified as readers/writers. These learners prefer textbooks, taking notes, readings, and printed handouts. Kinaesthetic learners prefer to learn through practical examples which also may involve other perceptual modes. **They** prefer practical examples, hands-on approaches in problem solving, and trial and error solutions to problems. Those who prefer obtaining information through multiple sources are identified as multi-modal. The VARK Learning styles inventory has gained immense popularity because of its face validity and simplicity, which Leite, Svinicki, and Shi (2010) confirmed using factor analysis to compare four multitrait-multimethod models to evaluate the dimensions in the VARK. They stated that the estimated reliability coefficients were adequate.

Method

This study employs a quantitative research design using analysis of subjective survey data. The study explores the research questions mainly by closely examining the responses of a small number of participants. The independent variable (i.e., the interaction environment) had two levels: AR environment and VR environment. The design of the study included learner preference as a moderating variable and the dependent variable of technology acceptance.

This research seeks to answer the following questions:

How does type of user interface (AR/VR) and learner preference affect the creative design process?

RQ1.1: How does interface type affect technology acceptance?

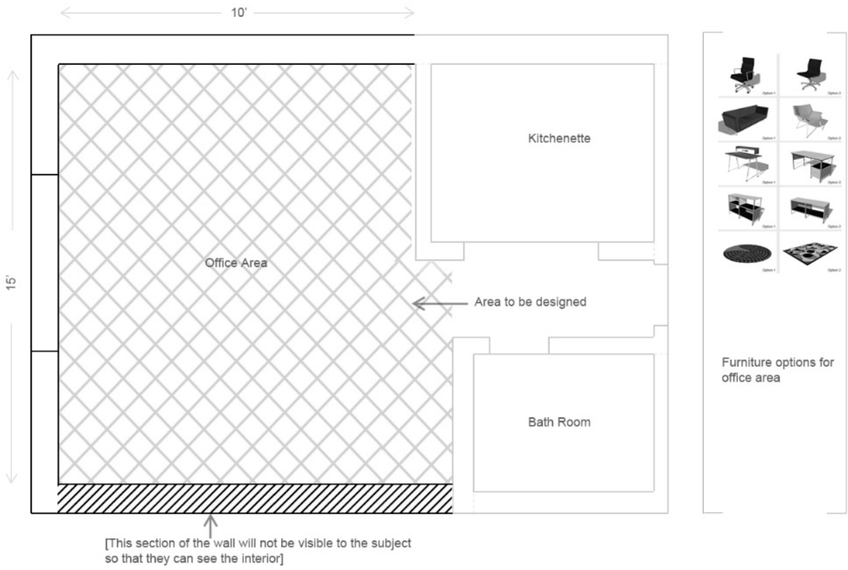
RQ1.2: How does learner preference interact with media type to affect technology acceptance?

Hypotheses for RQ1.1-1.2

- H1: The type of user interface used in design problem solving affects the perceived ease of use (PEU) of the user interface.
- H2: The type of user interface used in design problem solving affects the perceived usefulness (PU) of the user interface.
- H3: The type of user interface used in design problem solving affects the behavioural intention to use (IU).
- H4: The learner preference of the user moderates the PEU of the user interface.
- H5: The learner preference of the user moderates the PU of the user interface.

- H6: The learner preference of the user moderates the IU of the user interface.

Two design problem-solving interfaces were employed: an AR interface and a VR interface.



Both interfaces used a tabletop webcam and fiducial marker-based system. Thirty volunteers participated in the study. After approval by the institutional review board, the participants were chosen by purposeful sampling (Gall, Gall, & Borg, 2007). After announcing the research opportunity to design students (juniors and seniors) at a Midwestern university in the US, students were offered a chance to participate in the study. They were informed that there would be monetary incentive of $25 for participating. Volunteers were provided with copies of the informed consent form. The participants were then randomly assigned to one of the two interaction environments, AR/VR. Table 1 shows the demographic information of the participants.

Table 1. *Demographics in the Two Groups*

	Gender		Age		Academic	
	M	F	18-25	30-35	Senior	Junior
AR	0	15	15	0	6	9
VR	1	14	14	1	8	7

Figure 4. Floor plan of the office space.

The design problem was formulated in consideration of two main factors. The first was to provide a simple problem which would encourage the participants to focus on object manipulation, spatial and logical iterations, context, and user-behaviour issues, while also keeping in mind visual appeal, composition, environmental considerations, and ergonomic factors. The second consideration was previous studies that were conducted for a similar purpose.

All 30 participants responded to two questionnaires based on the technology acceptance model (post-test) and the VARK learning styles inventory (pre-test) to better understand how the interface affects the design process and human perception. In this study, the task was to arrange furniture within a small (15' X 10') office space (Figure 4). The floor plan was rectangular and had openings for windows and doors.

There were three main differences in the AR and VR environments. Firstly, in the VR environment a regular PC mouse was used as the interaction device and the manipulation was accomplished by dragging along the axis, while in the AR environment the fiducial markers were used in order to move and rotate the objects. Secondly, in the VR environment the screen transparency was set to 0 and in the AR environment it was set to 100. Thirdly, while in the AR environment each piece of furniture was assigned to a single marker, but in the VR environment all markers were printed on a single sheet, then moved and rotated using the PC mouse. The AR working environment is pictured in Figure 5 and the VR working environment is pictured in Figure 6.

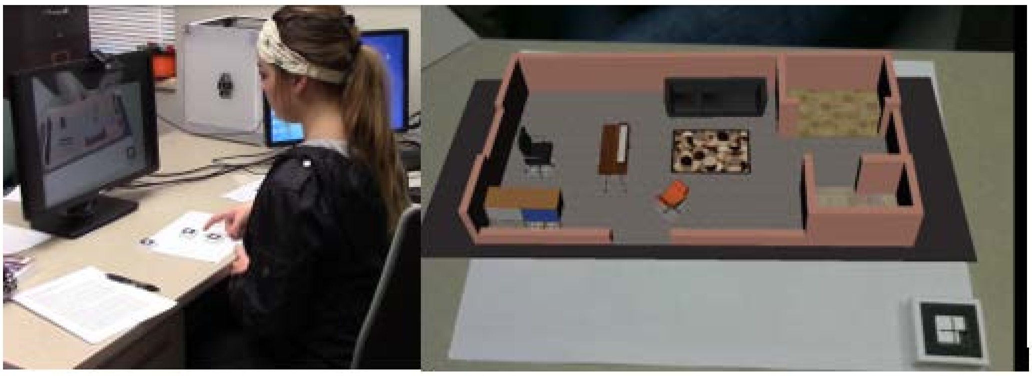


Figure 5. The augmented reality working environment.

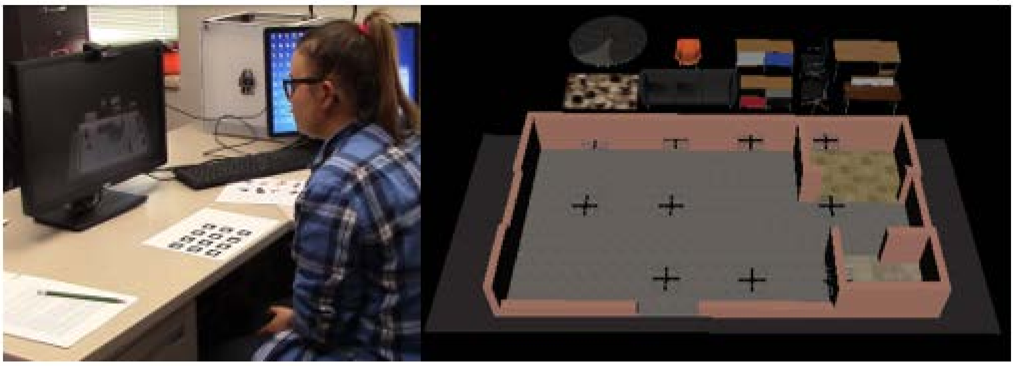


Figure 6. The virtual reality working environment.

Analysis and Discussion

Previous studies have shown that creativity is affected by intrinsic motivation. Furthermore, intrinsic motivation has been shown to be driven by the Perceived Ease of Use (PEU) of an assistive technology. PEU is one of the factors emphasized in the Technology Acceptance Model (TAM). In order to determine how the interface type affects learner preference, Perceived Ease of Use (PEU), Perceived Usefulness (PU), and Intention to Use (IU) were compared between the two interface types for two learning styles; visual and kinaesthetic learning styles.

Multivariate statistical software (SPSS version 20) was used to obtain descriptive statistics and to perform statistical analyses. A series of statistical tests were performed to test the research hypotheses. A one-way analysis of variance (ANOVA) was performed to compare the dependent variables (PU, PEU, and IU) between the two interface types. A two-way ANOVA was performed to explain the interaction between interface type and learner preference. To assess the relationship between PU and IU as well as PEU and IU, bivariate correlation coefficients (Pearson's *r*) were computed.

Reliability and Validity of the Instrument

The TAM instrument was adopted from an established TAM scale. The tool measures the subjective perceptions of technology use and has been previously validated in a number of studies (Davis, 1989; Davis, 1993; Dishaw & Strong, 1999; Igbaria, 1993; Igbaria, Schiffman, & Weickowski, 1994). Internal consistency of the measures in the TAM instrument was assessed by Cronbach's alpha (α) computed using SPSS. Cronbach's alpha ranges between 1 and 0, and internal consistency is considered greater as the value approaches 1. In the instrument used in this study, the PEU subscale consisted of nine items ($\alpha = .813$), and the PU subscale consisted of 5 items ($\alpha = .58$). In order to improve the α level for the PU subscale, one item was removed, which improved the Cronbach's α value to 0.65. DeVellis (1991) stated that an α value of 0.60 to 0.65 is undesirable but acceptable. The IU subscale consisted of two items ($\alpha = .79$).

The VARK questionnaire (Fleming & Mills, 1992) is an established learning style evaluation tool and was used without any modification, so checking the reliability or validity of the tool was not necessary.

Comparison of the Dependent Variables (PU, PEU and IU) between the Interface Types

A one-way ANOVA analysed the difference between interface type and the dependent variables. Table 2 shows the descriptive statistics for PEU, IU, and PU by interface type. ANOVA results for PU, IU and PEU are presented Table 3.

Table 2. *Descriptive Statistics for the Virtual and Augmented Reality Interfaces*

Dependent Variable	Independent Variable	Mean	SD
Perceived Usefulness (PU)	VR	4.83	1.08
	AR	5.90	0.60
Behavioural Intention to Use (IU)	VR	4.70	1.33
	AR	6.20	0.80
Perceived Ease of Use (PEU)	VR	5.52	0.95
	AR	6.23	0.26

Note: N = 15 *(In each group)*

Table 3. ANOVA Summary Table for Interface Type

Dependent Variable	Source	SS	df	MS	F	p
Perceived Usefulness	Between Groups	8.533	1	8.533	11.213	.002
	Within Groups	21.308	28	0.761		
	Total	29.842	29			
Behavioural Intention to Use	Between Groups	16.875	1	16.875	13.979	.001
	Within Groups	33.800	28	1.207		
	Total	50.675	29			
Perceived Ease of Use	Between Groups	3.793	1	3.793	7.804	.009
	Within Groups	13.608	28	0.486		
	Total	17.401	29			

The difference between the two interface types was significant for all three dependent variables: PU, $F(1,28) = 11.21$, $p = .002$); IU, $F(1,28) = 13.979$, $p = .001$); and PEU, $F(1,28) = 7.804$, $p = .009$). All three dependent variable means were significantly higher in the AR interface type, PU: $M = 5.90$, $SD = 0.60$; PEU: $M = 6.23$, $SD = 0.26$; and IU: $M = 6.20$, $SD = 0.80$, compared to the VR interface type, PU: $M = 4.83$, $SD = 1.08$; PEU: $M = 5.52$, $SD = .95$; and IU: $M = 4.70$, $SD = 1.33$.

Comparison of the Dependent Variables between Interface Type and Learner preference

In order to understand the interaction between interface type (independent variable) and learner preference (moderating variable) on the dependent variables (PU, PEU and IU), a two-way ANOVA was performed for each of the dependent variables. See Table 4 & 5.

Table 4. Descriptive Statistics for Perceived Usefulness

Interface Type	Learner Preference	Mean	Std. Deviation	N
VR	Visual	4.25	.50000	3
	Aural	6.08	.52042	3
	Read/Write	4.81	.42696	4
	Kinaesthetic	4.94	1.06800	4
	Multimodal	2.50	.	1
AR	Visual	6.15	.54772	5
	Aural	5.67	.14434	3
	Read/Write	5.25	.00000	3
	Kinaesthetic	6.42	.80364	3
	Multimodal	5.75	.	1

Table 5. Two-Way ANOVA Summary Table for the Effect of Learner Preference and Interface Type on Perceived Usefulness

Source	SS	df	MS	F	p
Interface Type	10.127	1	10.127	26.849	.000
Learner preference	6.249	4	1.562	4.142	.013
Interaction	7.956	4	1.989	5.273	.005
Error	7.544	20	.377		
Total	893.875	30			

Note. R^2 = .747 and adjusted R^2 = .633

The effect of the interaction between the interface type and learning style on the PU is significant, $F(4,20) = 5.273$, $p < .005$. The main effect for interface type on PU is also significant, $F(1,20) = 26.85$, $p < .001$. Furthermore, the main effect of learner preference on PU is significant, $F(4,20) = 4.142$, $p < .013$.

Table 6. Differences in Perceived Usefulness between Augmented and Virtual Reality Interface by Learner preference

Learner Preference	Mean Difference	SE	*p*

Visual	-1.900*	.449	.000
Aural	.417	.501	.416
Read/Write	-.437	.469	.362
Kinaesthetic	-1.479*	.469	.005
Multimodal	-3.250*	.869	.001

**p* < .01

The pairwise comparisons suggested that the mean PU score was significantly higher in the AR environment than the VR environment for kinaesthetic learners. Furthermore, the mean PU was significantly higher in the AR environment than the VR environment for visual learners. For PEU and IU, the interaction between interface type and learner preference was not significant (p = 0.092 and 0.074 for PEU and IU, respectively).

Because the multimodal learner category only had two participants (one for each interface type), the two participants were removed from the data set and the two-way ANOVA was rerun to observe any difference in the results. Removing these two participants made no difference in the results obtained for the interaction between learner style and interface type on PU, PEU, or IU.

Relationships between Perceived Usefulness and Behavioural Intention to Use as well as Perceived Ease of Use and Behavioural Intention to Use

To investigate the relationship of PEU and PU on the IU as suggested by the TAM, bivariate correlations (Pearson's *r*) were calculated. As expected and predicted by the TAM, all PU, PEU, and IU were positively but not strongly correlated (see Table 7).

Table 7. Correlations among Variables

		Perceived Usefulness(PU)	Behavioural Intention to Use(IU)
Behavioural Intention to Use (IU)	Pearson's r	.689**	
	Sig. (2-tailed)	.000	
Perceived Ease of Use (PEU)	Pearson's r	.480**	.589**
	Sig. (2-tailed)	.007	.001

Note: N = 30 ** p < .001

Summary of Findings

In this study, two research questions were investigated: How does interface type affect technology acceptance? And how does learner preference interact with the interface type to affect technology acceptance? Hypotheses H1 through H6 were tested.

> *H1: The type of user interface used in design problem solving affects the Perceived Ease of Use (PEU) of the user interface.*
>
> *H2: The type of user interface used in design problem solving affects the Perceived Usefulness (PU) of the user interface.*
>
> *H3: The type of user interface used in design problem solving affects the Intention to Use (IU).*

According to results of the ANOVA, the difference between the two interface types was statistically significant for all three dependent variables, PU, IU, and PEU. All three variables had a higher value in the AR interface. The conclusion is that participants found AR to be easier to use and more useful and were more inclined to use it in the future than VR. Null hypotheses for H1-H3 were rejected.

> *H4: The learner preference of the user moderates the PEU of the user interface.*
>
> *H5: The learner preference of the user moderates the PU of the user interface.*
>
> *H6: The learner preference of the user moderates the IU of the user interface.*

According to the results of the two-way ANOVA, the interaction between the interface type and learner preference was significant for PU. As expected, the PU score was significantly higher in the AR environment than the VR environment for kinaesthetic learners. Contrary to expectations, the mean PU was also significantly higher in the AR environment than the VR environment for visual learners. The null hypothesis for H5 was rejected.

Research has shown that extrinsic motivation for using assistive technology is captured by the PU construct in the TAM (Davis, 1989; Venkatesh & Davis 2000; Venkatesh & Speier, 2000). Furthermore, Venkatesh, (2000) stated that intrinsic motivation is related to PEU.

PEU is a measurement of intrinsic motivation that enhances the creative design process. PU is a means of measuring extrinsic motivation. For PEU and IU, the interaction between interface type and learner preference was not significant. From these results the conclusion cannot be made that learner preference moderates the creative design process in a given interface type. Therefore, the null hypotheses for H4 and H6 were not rejected.

As expected and as proposed in the TAM, this study found positive correlations between IU and PU as well as IU and PEU. This result validates previous results and the methodology used in this study.

Participants rated PU, PEU, and IU higher for the AR interface. The conclusion is that kinaesthetic and visual learners found the AR environment more useful than the VR environment.

Conclusions

The main research question of the study focused on a relationship between user preference and creativity in the design process when using Augmented Reality (AR) and Virtual Reality (VR). The AR environment was operationalized as an interface that offered tangible interaction, as compared to VR which functioned within the Windows, Icons, Menus and Pointers (WIMP) paradigm.

This study provided information on how user preference affects the use of different interfaces. The results suggest that participants perceived AR to be easier to use, more useful and were more inclined to use it in the future than VR. As expected, kinaesthetic learners found the AR environment more useful than the VR environment. However, contrary to expectations, visual learners found the AR environment more useful than the VR environment. The AR interface used in this study was similar to the VR interface in every way except for the method of interaction and interface transparency. However, the interaction in the AR interface was achieved by using a fiducial marker, which may not be the ideal method of interaction for AR. This might be a factor to explain the unexpected result that visual learners found AR to be more useful than VR. True tangible interaction for AR may be achieved by using devices such as a leap motion controller that provide tangible interaction with virtual objects. From these results, the conclusion cannot be made that learner preference moderates the creative design process in a given interface type.

This study has theoretical, methodological, and practical implications. The implications of the study provide designers and design educators with insights into the selection of different types of interfaces that affect the creative design process. Furthermore, the results of the study offer suggestions to developers of instructional and educational media and materials to create content for different types of interfaces. The theoretical framework established the connection between Perceived Ease of Use (PEU) and creativity through intrinsic motivation. While learner preference did not significantly affect creativity, technology acceptance was higher for the AR environment, and learner preference affected Perceived Usefulness (PU). These theoretical implications can contribute practical insights to multiple domains on using different interface types in the design process.

From a practical standpoint, the findings of this study contribute to helping designers and design educators use interfaces such as AR and VR in the design process. The results of the current study show how learner preference moderates user acceptance of different interface types and may affect the creative design process. Even though there was no relationship between creativity in the design process and learner preference under the AR and VR interfaces, the learners' PU, PEU, and Behavioural Intention to Use (IU) were all significantly higher in the AR interface than in the VR interface. This finding is consistent with previous findings on AR and user acceptance (Chandrasekera, Yoon & Balakrishnan, 2012). These theoretical implications can contribute practical insights to multiple domains on using different interface types in the design process.

Limitations

The current study was designed with numerous methods of limiting errors and enhancing the validity of the research protocol in investigating how user learner preferences affect the use of Augmented Reality (AR) and Virtual Reality (VR) in the creative design process. However, as in all research of an exploratory nature, there are some unavoidable limitations.

First, the participants were college students in a design program at one Midwestern college in the United States. Most of the students were living in the same region. The study focused on design and the design process, and the students that were recruited were design students who were in their junior and senior years of study. Even though the participants were randomly assigned to the AR or VR group, six seniors and nine juniors were in the AR group, while eight seniors and seven juniors were in the VR group. This unequal distribution might have affected the results of the study because the senior students are more experienced in the design process than the junior students. Another major limitation was the unequal gender distribution: 29 out of 30 participants were female.

The second limitation was the small number of participants recruited in the study. One of the reasons for the small sample size was obtaining participants for the research study. The entire data collection took place from December, 2014 to April, 2015. Although an incentive was offered, the need to dedicate some time out of their busy and limited schedules contributed to the students' decision to refrain from participating in the study.

References

Amabile, T. M. and S. S. Gryskiewicz (1987). *Creativity in the R&D laboratory.* Greensboro, NC :Center for Creative Leadership.

Amabile, T. M. (1987). The motivation to be creative. *Frontiers of creativity research: Beyond the basics*, 223-254.

Amabile, T. M. (1985). Motivation and creativity: Effects of motivational orientation on creative writers. *Journal of personality and Social Psychology, 48*(2), 393-399.

Anasol, P.-R., Ferreyra-Olivares, E., & Alejandra, P. (2013). Stories of the virtual mind. In *Proceedings of the Creative Science 2013 (CS'13), 18-27*.

Atkinson, E. S. (2004). *A comparison of the relationship between creativity, learning style preference and achievement at GCSE and degree level in the context of design and technology project work.* Paper presented at the DATA International Research Conference.

Ausubel, D. P., Novak, J. D., & Hanesian, H. (1968). *Educational psychology: A cognitive view.* New York: Holt, Rinehart and Winston.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators & Virtual Environments*, *6*(4), 355-385.

Baer, J. (1997). Gender differences in the effects of anticipated evaluation on creativity. *Creativity Research Journal*, *10*(1), 25-31.Baer, J. & J. C. Kaufman (2008). Gender differences in creativity. *Journal of Creative Behavior, 42*(2), 75-105.

Bell, B., Koch, J., & Green, B. (2014). Assessing Learning Styles of Pharmacy Students Using the VARK Questionnaire. Unpublished presentation, Butler University.

Briggs, K. C. (1976). *Myers-Briggs Type Indicator.* Palo: Alto, CA: Consulting Psychologists Press.

Bryson, S. (1995). Approaches to the successful design and implementation of VR applications. *Virtual Reality Applications*, 3-15.

Casakin, H. & S. Kreitler (2010). Motivation for creativity in architectural design and engineering design students: implications for design education. *International Journal of Technology and Design Education, 20*(4), 477-493.

Chandrasekera, T., Yoon, S. Y., & Balakrishnan, B. (2012). *Digital orthographic projections in architectural representation: Augmented reality based learning*. Paper presented at the 16th Biannual Conference of the Design Communication Association Stillwater, Oklahoma.

Collins, M. A. & T. M. Amabile (1999). Motivation and creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 297 – 312). Cambridge, England: Cambridge Univ. Press.

Curry, L. (1983). *An organization of learning styles theory and constructs*. Paper presented at the 67th Annual Meeting of the American Educational Research Association (Montreal, Quebec, April 11-15).

D'Souza, N. S. (2006). *Design Intelligences: A Case for Multiple Intelligences in Architectural Design* (Doctoral dissertation, University of Wisconsin--Milwaukee).

D'Souza, N. (2009). Revisiting a vitruvian preface: The value of multiple skills in contemporary architectural pedagogy. *Architectural Research Quarterly, 13*(2), 173-182.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly,* 319-340.

Davis, F. D. (1993). User acceptance of information technology: system characteristics, user perceptions and behavioral impacts. *International Journal of Man-machine studies, 38*(3), 475-487.

Demirbaş, O. & H. Demirkan (2003). Focus on architectural design process through learning styles. *Design Studies, 24*(5), 437-456.

DeVellis, R. F. (1991). *Scale development: Theory and applications*. Newbury Park, CA: Sage.Dishaw, M. T. & Strong, D.M. (1999). Extending the technology acceptance model with task–technology fit constructs. *Information & Management, 36*(1), 9-21.

Dishaw, M. T., & Strong, D. M. (1999). Extending the technology acceptance model with task–technology fit constructs. Information & management, 36(1), 9-21.

Drago, W. A. & Wagner. R. J. (2004). VARK preferred learning styles and online education. *Management Research News, 27*(7), 1-13.

Dunn, R. (1993). Learning styles of the multiculturally diverse. *Emergency Librarian, 20*(4), 24-32.

Durling, D., Cross, N., & Johnson, J. (1996). *Personality and learner preferences of students in design and design-related disciplines.* Paper presented at the IDATER 1996 Conference, Loughborough, Loughborough University.

Eishani, K. A., Saa'd, E. A., & Nami, Y. (2014). The relationship between learning styles and creativity. *Procedia-Social and Behavioral Sciences, 114,* 52-55.

Felder, R. M. & Silverman, L. K. (1988). Learning and teaching styles in engineering education. *Engineering Education, 78*(7), 674-681.

Fischer J., Cunninham, D., Bartz, D., Wallraven, C., Bulthoff, H., Stasser, W. (2006). Measuring the discernability of virtual objects in conventional and stylized augmented reality. In *Proceedings of Eurographics Symposium on Virtual Environments* (2006), pp. 53–61.

Fleming, N. D.& C. Mills, C. (1992). Not another inventory, rather a catalyst for reflection. *To Improve the Academy, 11*, 137–143.

Fleming, N. D. (2001). Teaching and Learning Styles: VARK Strategies. Honolulu Community College, Honolulu, 2001, p. 128.

Friedel, C., & Rudd, R. (2006). Creative thinking and learning styles in undergraduate agriculture students. *Journal of Agricultural Education, 47*(4), 102.

Gall, M. D., Gall, J. P., & Borg, W. R. (2007). Collecting research data with questionnaires and interviews. *Educational research: An introduction*, 227-261.

Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences*: NY: Basics.

Grier, R., Thiruvengada, H., Ellis, S., Havig, P., Hale, K., & Hollands, J. (2012). Augmented Reality–Implications toward Virtual Reality, Human Perception and Performance.

Harnad, S. (2006). Creativity: method or magic? *Hungarian Studies, 20*(1), 163-177.

Hennessey, B. A., & Amabile, T. M. (1998). Reality, intrinsic motivation, and creativity. *American Psychologist, 53,* 674–675.

Huang, W., Alem, L., & Livingston, M. (2012). *Human factors in augmented reality environments.* New York: Springer Science & Business Media.

Igbaria, M. (1993). User acceptance of microcomputer technology: an empirical test. *Omega, 21*(1), 73-90.

Igbaria, M., Schiffman, S. J., & Wieckowski, T. J. (1994). The respective roles of perceived usefulness and perceived fun in the acceptance of microcomputer technology. *Behaviour & Information Technology, 13*(6), 349-361.

Isham, D. D. (1997). Developing a computerized interactive visualization assessment. *The Journal of Computer-Aided Environmental Design and Education* 3(1). Online. Scholarly Communications Project, University Libraries, Virginia Tech. Retrieved July 7, 2015 from: http://scholar.lib.vt.edu/ejournals/JCAEDE/v3n1/

Ishii, H. (2007). Tangible user interfaces. In A. Sears & J.A. Jacko (Eds.), The human-computer interaction handbook. Fundamentals, evolving technologies, and emerging applications, (pp. 469–487). Hillsdale, NJ: Lawrence Erlbaum Associates.

James, W. B., & Gardner, D. L. (1995). Learning styles: Implications for distance learning. *New Directions for Adult and Continuing Education, 1995*(67), 19-31.

Kassim, H. (2013). The relationship between learning styles, creative thinking performance and multimedia learning materials. *Procedia-Social and Behavioral Sciences, 97*, 229-237.

Keefe, J. (1979). Learning style: An overview. NASSP's Student learning styles: Diagnosing and proscribing programs (pp. 1-17). Reston, VA. National Association of Secondary School Principle. Retrieved July 7, 2015, from http://www.nwlink.com/~donclark/hrd/styles.html#sthash.SbepFXmt.dpuf

Koestner, R., Ryan, R. M., Bernieri, F., & Holt, K. (1984). Setting limits on children's behavior: The differential effects of controlling vs. informational styles on intrinsic motivation and creativity. *Journal of Personality, 52*(3), 233-248.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice-Hall.

Kreitler, S., & Casakin, H. (2009). Motivation for creativity in design students. *Creativity Research Journal, 21*(2-3), 282-293.

Kvan, T., & Jia, Y. (2005). Students' learning styles and their correlation with performance in architectural design studio. *Design Studies, 26*(1), 19-34.

Lau, W. W., Yuen, A. H., & Chan, A. (2015). Variable-Centered and Person-Centered Approaches to Studying the VARK Learning Style Inventory *New Media, Knowledge Practices and Multiliteracies* (pp. 207-216). NY: Springer.

Leite, W. L., Svinicki, M., & Shi, Y. (2010). Attempted validation of the scores of the VARK: Learning styles inventory with multitrait–multimethod confirmatory factor analysis models. *Educational and Psychological Measurement, 70*(2), 323-339.

Lubart, T. I. (1999). Creativity across cultures. In R. J. Sternberg (Ed.), *Creativity research handbook* (pp. 339–350). Cambridge, England: Cambridge University Press.

Lujan, H. L., & DiCarlo, S. E. (2006). First-year medical students prefer multiple learning styles. *Advances in Physiology Education, 30*(1), 13-16.

Marcy, V. (2001). Adult learning styles: How the VARK Learning Styles Inventory can be used to improve student learning. *Perspectives on Physician Assistant Education, 12*(2), 117-120.

Newland, P., Powell, J. A., & Creed, C. (1987). Understanding architectural designers' selective information handling. *Design Studies, 8*(1), 2-16.

Ogot, M., & Okudan, G. E. (2007). Systematic creativity methods in engineering education: a learning styles perspective. *International Journal of Engineering Education, 22*(3), 566-576.

Pearsall, M. J., Ellis, A. P., & Evans, J. M. (2008). Unlocking the effects of gender faultlines on team creativity: Is activation the key? *Journal of Applied Psychology, 93*(1), 225.

Potur, A., & Barkul, O. (2007). Rethinking the entrance to architectural education: A critical overview*. Proceedings of the DesinTrain Congress, Amsterdam, The Netherlands*.

Runco, M. A. (2005). Motivation, competence, and creativity. In A. J. Elliot & C. S. Dweck (Eds.), *Handbook of competence and motivation* (pp. 609–623). New York: Guilford

Shalley, C. E., Zhou, J., & Oldham, G. R. (2004). The effects of personal and contextual characteristics on creativity: Where should we go from here? *Journal of Management, 30*(6), 933-958.

Tsai, K. C., & Shirley, M. (2013). Exploratory Examination of Relationships between Learning Styles and Creative Thinking in Math Students. *International Journal of Academic Research in Business and Social Sciences, 3*(8), 506-519.

Thurstone, L. L. (1938). Primary mental abilities. *Psychometric Monographs*. Chicago: Unviersity of Chicago Press.

Thelen, H. A. (1954). *Dynamics of groups at work*. Chicago: University of Chicago.

Venkatesh, V. (2000). Determinants of perceived ease of use: Integrating control, intrinsic motivation, and emotion into the technology acceptance model. *Information Systems Research, 11*(4), 342-365.

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science, 46*(2), 186-204.

Venkatesh, V., & Speier, C. (2000). Creating an effective training environment for enhancing telework. *International Journal of Human-Computer Studies, 52*(6), 991-1005.

Wehrwein, E. A., Lujan, H. L., & DiCarlo, S. E. (2007). Gender differences in learning style preferences among undergraduate physiology students. *Advances in Physiology Education, 31*(2), 153-157

Wolfradt, U., & Pretz, J. E. (2001). Individual differences in creativity: Personality, story writing, and hobbies. *European Journal of Personality, 15*(4), 297-310.

Reflecting on the architecture curriculum through a survey on career switching

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Abstract
Due to the deteriorating investment environment, many real-estate companies in China have started transferring their business out of the construction industry. This leads to the shrinkage of the design market and also architects' salary. A great number of architects have switched career to maintain the same living quality as before. Meanwhile, architectural education in China is not able to integrate itself with emerging science and technologies, losing possibilities to explore new employment channels for its graduates. There is a huge gap between qualities needed in the current or future labour market and the architectural education in schools. An online survey was conducted to investigate the current state of architects' career shifting, trying to expose the problem mentioned above. In the second part of this paper, education missions from 50 universities are analysed and detailed education curriculums from three top universities are scrutinised. At the end, the education boundary is suggested to be reconstructed from three aspects: integrating the emerging technologies; reducing unnecessary content; and training in self-learning skills.

Key words
architectural education; Architecture design; Architect; Education development; Building design; China

Introduction
The architect used to be a favourable career choice among young Chinese, due to the high salary and social identity. With regard to a ranking (Speiyou, 2013), in the year 2012, new architectural degree holders had the highest salary among different major graduates, amounting to 4453 Chinese Yuan per month. However, statistics from the biggest job searching website Jobhui, whose yearly salary data was based on more than 30,000,000 samples, show that since the year 2011 architects' income has started decreasing (Figure 1). By comparing the salary prediction of architects with the average number of all industries in Shanghai, the increasing unimportance of architecture as a career in the whole society can be confirmed. What is worse, some design companies were already unable to pay the year-end award which is a big part of income for Chinese architects, causing several scandals (ARCHCOLLEGE, 2016). Under this macro environment, many architects switch their career for a higher salary and social identity. It is reasonable for architects to offer services that do not belong to their traditional duties but that are needed in the market (Jann, 2010). Carnegie Foundation made a survey in the year 1996 and found that 22% of architecture graduates in one school switched careers (Ball, 2004).

Nevertheless, the swift development of building technologies actually already has brought many new possibilities for the architects, which still have not been realised by educators. Actually, the reality is even worse because architectural teaching is already lagging behind contemporary construction practice, due to most of the teachers lacking practical experience on real projects. Hence, students are getting the education which is already out of date in the job market, let alone those recently developed technologies. In order to deeply analyse this phenomenon and find some solutions, an online survey aiming to probe the architects' career switching was published. Results of the survey shed a light on the gap between job market and school education. In the second part, this paper focuses on the boundary of education content, with a vision of the inadequacy and redundancy in the existing educational system. The whole study has significance in the development of architectural education and will be beneficial for educators and schools.

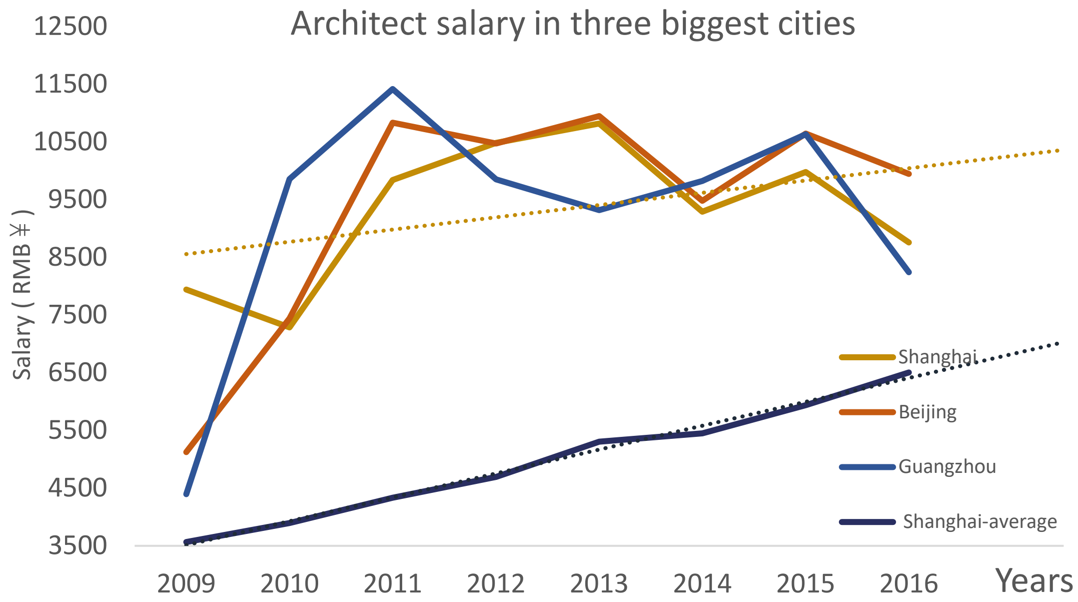


Figure1. Salary of architects decreases in China （Statics from website jobhui.com and Shanghai Municipal Statistics Bureau, elaborated by author）

Online survey

Respondents' situation

The questionnaire has been published on online survey website "Sojump" since 8th February 2017 and the link was diffused by posting it on various social media sites. Up to the 8th February 2018, we have 339 respondents whose IP addresses were from 28 provinces of China (15 persons of them were from abroad). The top five places are Beijing, Guangdong, Jiangsu, Shanghai and Henan. Around 70% of the answer sheets were submitted through mobile phones while the rest were sent back through computers. The age, education background, and licensed condition of these 339 respondents are illustrated in the Figure 2. About seven tenths of them had a bachelor degree while 27% and 1.5% of these people hold a master degree or a PhD respectively. A major part of these former architects were not certified by the authority while 9% of them were 1st or 2nd level certified architects in China. Due to varieties of limitations, it was impossible to get the total number of architects switching their careers of the whole country. The demographics of this online survey is limited but none-the-less unveils the existing conditions in some degree with a broad spread of respondents.

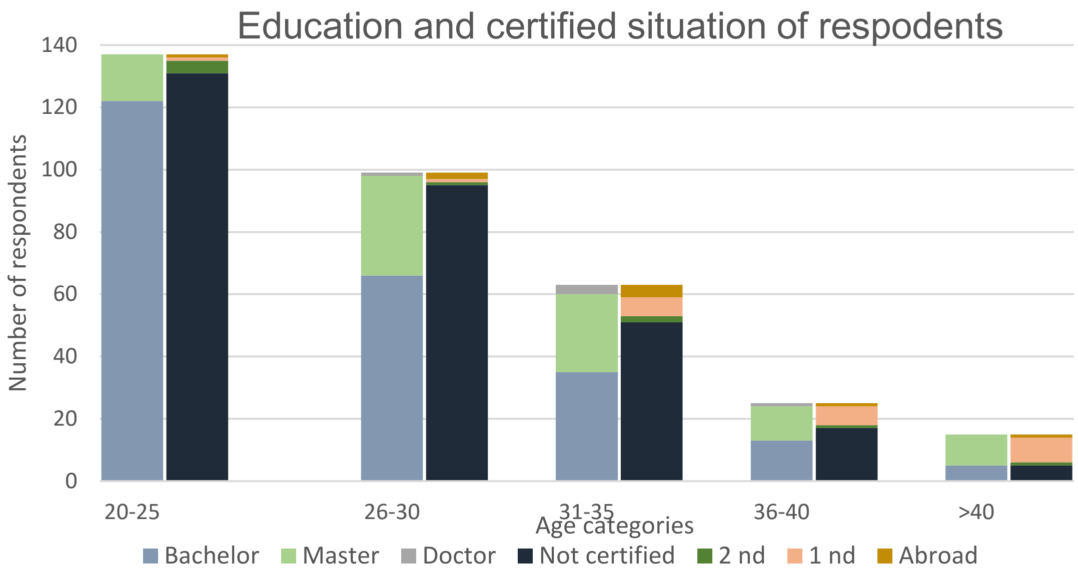


Figure 2.

Education background and accredited situation

Conditions on career shifting

Survey results identify that around half architects left the career due to overwhelming workload or unsatisfactory salary (Figure 3). Another one-quarter of them lost interest in this major or found something more attractive. Only thirteen persons were unable to find a job as an architect then passively switched their career. The ratio of self-employment is 23% while the others still worked as an employee. Afterwards, the survey focused on the specific conditions of their new careers (Figure 4). Around two fifths of the people still stayed in the construction industry while the other three fifths went to a totally new industry. Despite this, nearly 90% respondents had a new job still with regard to designing, and many people believed that their architectural education background played a helpful role in new occupations.

Figure 5 shows specific industries chosen by the respondents for new careers. Real Estate Company is a traditional option for architects to divert the profession, and it still occupies the first place herein. IT industry ranks a surprising second place while the culture industry takes the third place. Interactive design is in the 7th position and the animation industry ranks the 9th respectively. Virtual reality also appears on the ranking, with more popularity than fashion design and furniture design which are regular choices for architects.

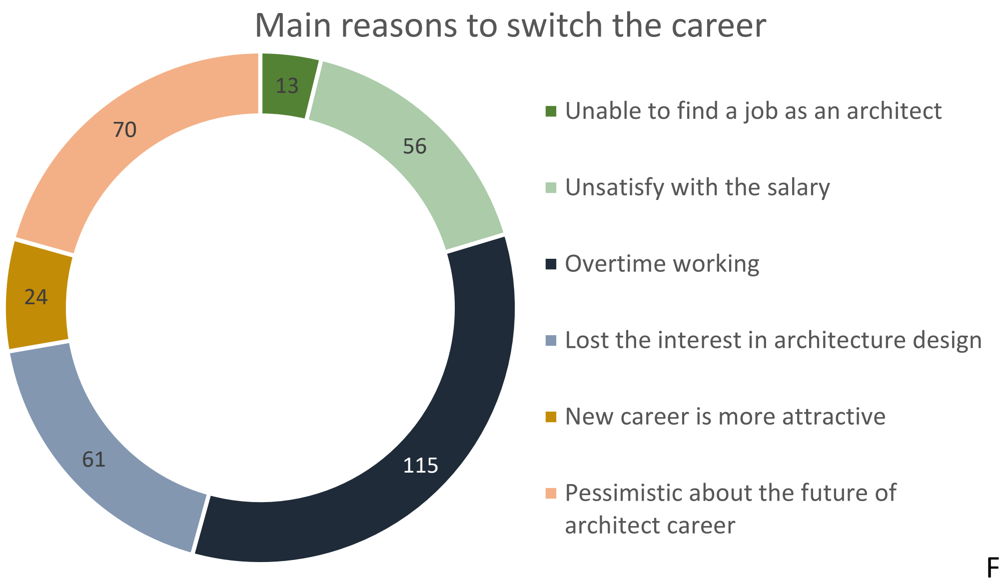
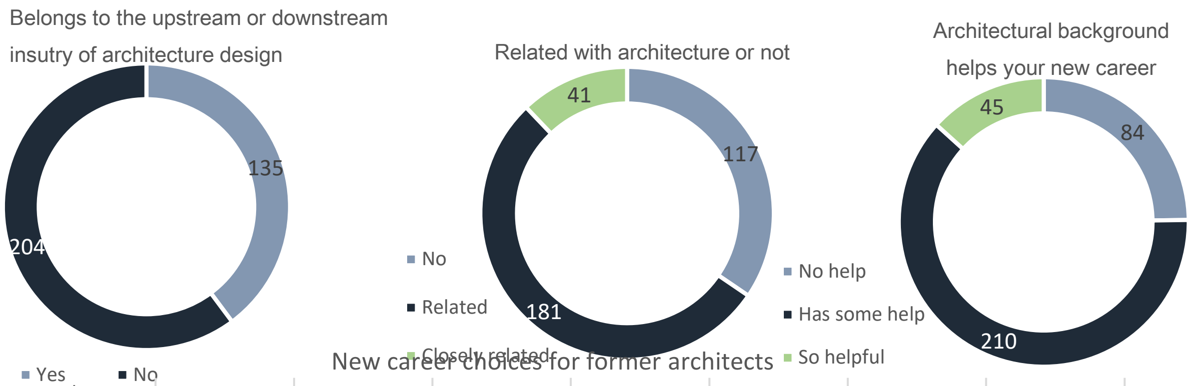


Figure 3.

Reasons to switch the career



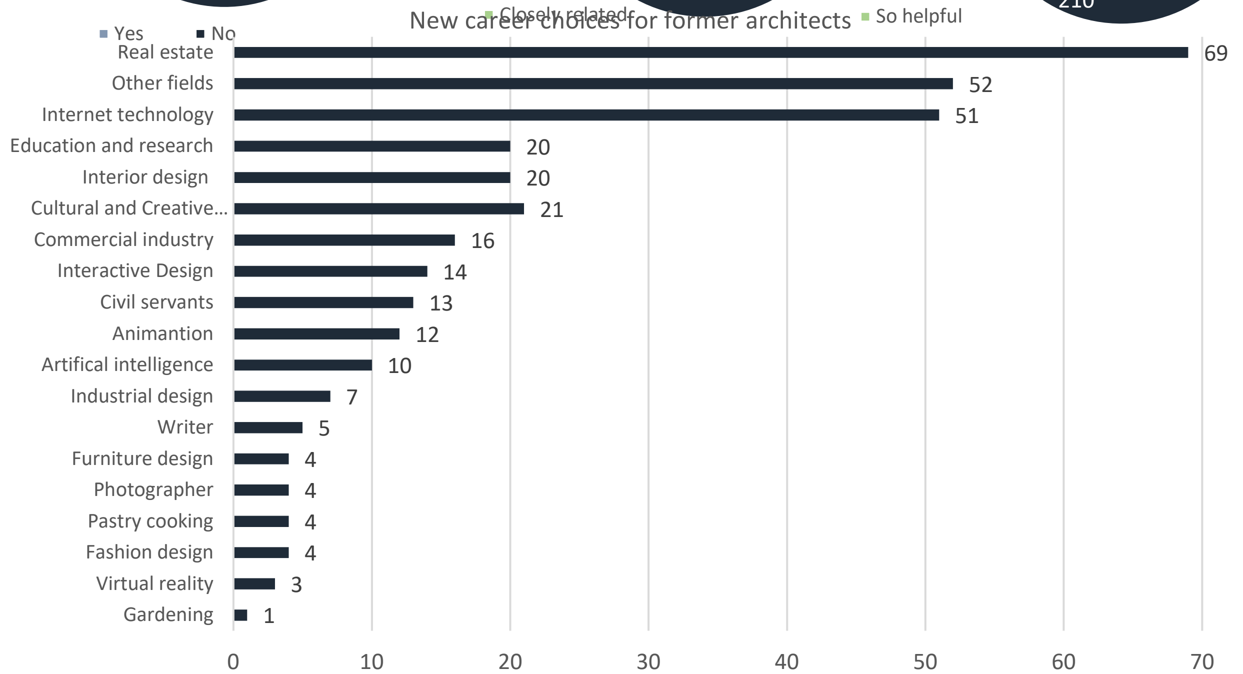


Figure 4. Conditions on new careers

Figure 5. New career choices of former architects

Evaluation on the architectural education

The quality of university education was also asked in the questionnaire. Around seven tenths of people deemed that there is no progress or even worse. The most beneficial and helpful course during respondents' education was the Aesthetic Training, while Logical Training and Verbal Expressing were positioned the second and the third respectively. When they were asked about course contents, four fifths of respondents were concerned that the majority of knowledge taught in universities actually was out of date at that time. The familiarity with cutting-edge technologies when they graduated can prove this. Around 83% of them were unfamiliar with technologies on the building energy efficiency, and this number comes to 84% towards to the Virtual Reality, 87% to the Artificial Intelligence. One-third of them believed that these new technologies would promote the architecture industry and it is a pity it is not learned in schools. Meanwhile, around 83% respondents considered that there is not enough educational resource to support them working outside the architecture design field. Only seven persons gained enough resources training them for jobs besides architecture designing.

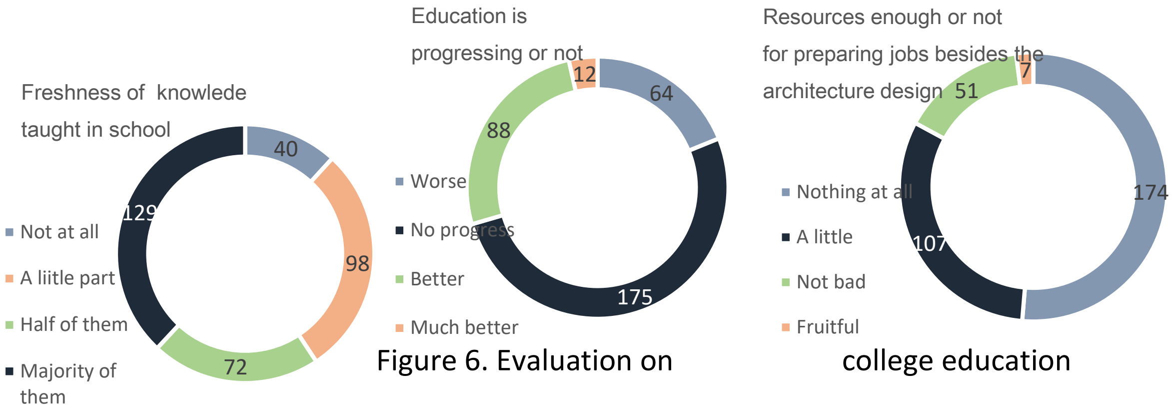


Figure 6. Evaluation on college education

Discussions

China still has adequate designing jobs for architects (only thirteen respondents were unable to find a job as an architect) but the rising dissatisfaction with salary and working environment make architects hold a pessimistic view on the profession. They have perceived the necessity to alter the career in advance, not waiting to be passively compelled. The survey above also identifies that the traditional role of architects is dying while innovative technologies are bringing new opportunities for architects. Architects' new choices are not only constrained in regular options like furniture and fashion design but also extending to technology-demanding industries like IT and Virtual Reality.

The majority of investigated people were not satisfied with the received education. They insisted that teachers without the latest experience on practical projects should be excluded from design studio teaching. It means that teachers have to play double roles: an educator and also a practitioner. Besides that, the education they received neither realized the original claim in a large number of admission guides, which said that graduates from their architecture major can shoulder a variety of jobs besides being an architect.

Architecture designing is a service industry heavily depending on the market (Cuff, 1992). As the urbanism (urbanisation) process in China is slowing down, the architectural education system should realise the necessity to change and fit the societal needs. The main initiative of following chapters is to revise the existing architectural curriculum, which currently is unsuitable and full of outdated knowledge.

Reflecting on the architectural curriculum

Knowledge boundary as an architect

Providing architectural education in a limited period is not easy and it needs to smartly define the architectural knowledge boundary (Mahalingam, 2007). Based on authors' practical experience and also designer role analysis by Krippendorf (Charalambous & Christou, 2016), the knowledge required to be an architect is categorised into five key domains and also sub-categories around them (Figure 7): art & design, science, technology, construction and politics. Figure 7 shows that the greater part of knowledge is located in the art category while the construction domain contains the least knowledge points. Out of the boundary, there are several points related to the specific domain but do not belong to the whole architecture field. Figure 7 also demonstrates more working chances but on the orientation of art outside the border. Then the politics side also has several options outside but the science and technology domain do not have outside knowledge points due to the learning threshold for architects. It hardly happens that architects switch profession to be a scientist or building structure engineer. Nevertheless, the combination of technology and art also offers many other possibilities which will be discussed in the next sections. Thence, new possibilities should be explored and integrated into the education programmes.

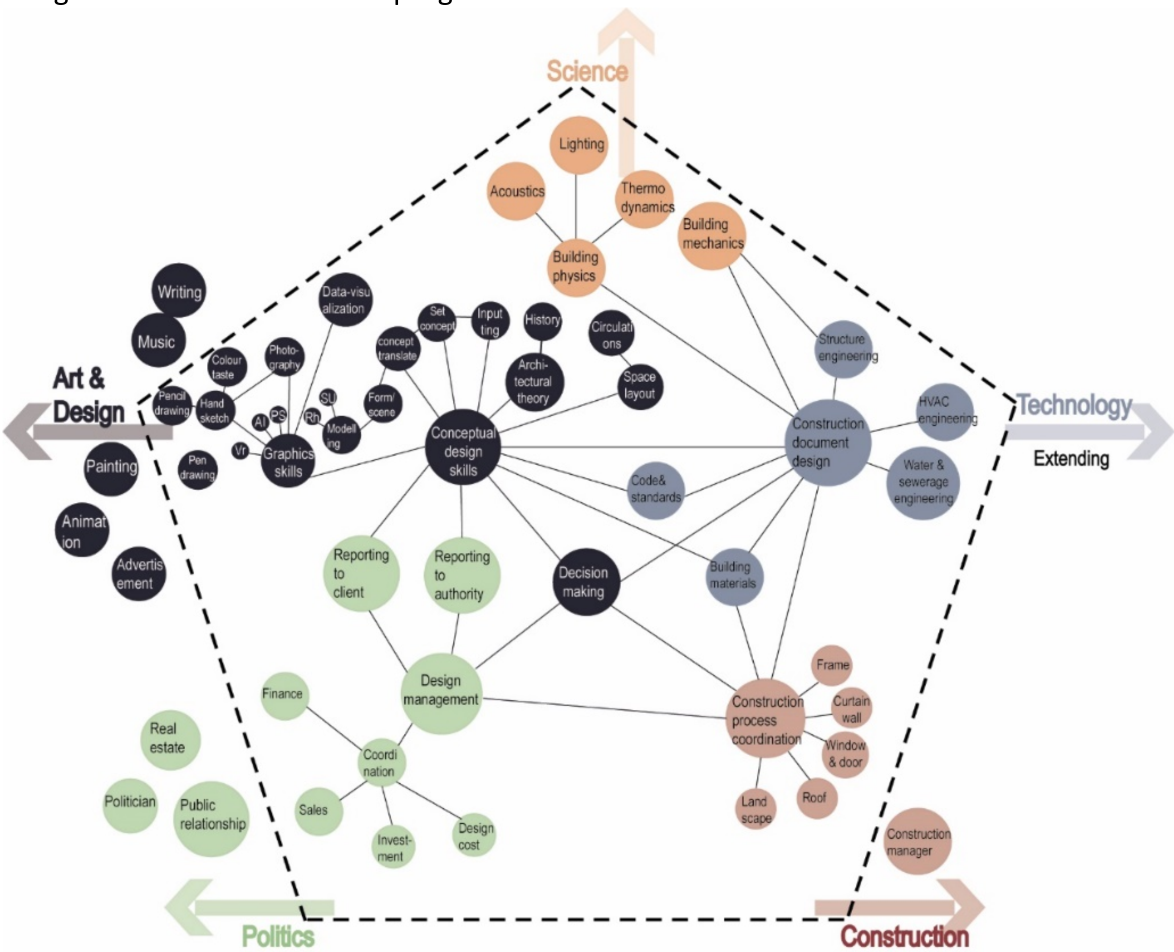


Figure 7. Knowledge boundary of architects, elaborated by the author

Knowledge teaching in universities

In order to analyse the school side with the theory discussed above, we randomly collected architecture teaching missions from fifty Chinese universities. Then a keyword cloud showing focuses of these fifty missions was automatically generated, according to the frequency of word appearance in missions (Figure 8). Besides the word *architecture design*, other main keywords are *technology, engineering, city, theory, construction*. We can contract a common mission from all of them: training high-level engineering professions who are adjusted to the market evolution. To get closer, three representative universities (Table 1), out of eight top architecture departments in China (Wikipedia, 2015), are picked for the curriculum investigation. University names are hidden to avoid unnecessary disputes. Three curriculums of five-year-BArch programmes were all retrieved from their official websites. Some unrelated courses, like Physical Education and China's Modern History, are not counted as major courses. Neither are internships, selective courses, and final thesis included. Results are expressed with radar maps in Figure 9. It can be found that “Art & Design” is the main part of all three curriculums while technology is the second important sector. The other three domains actually played a slight role in all three curriculums.

Figure 8. Keyword cloud of architectural education missions in China.

	University A	University B	University C
Time of the latest version	Year 2013	Year 2016	Year 2014
Total credits for graduation	200	237	213
Total credits of major courses	133	156	179
Credits related to art & design	100 (75%)	112 (71.8%)	121 (67.7%)
Credits related to science	10 (7.5%)	9 (5.8%)	11 (6.1%)
Credits related to technology	16 (12.5%)	33 (21.2%)	45 (25.1%)
Credits related to construction	3 (2%)	0 (0%)	0 (0%)
Credits related to politics	4 (3%)	2 (1.2%)	2 (1.1%)
Credits for Virtual Reality	N/A	2 (Selective course)	N/A
Credits for coding courses	N/A	2.5 (VB.NET)	3 (VB)
Credits for mathematics	5 (calculus); 2 (architectural math)	6 (advanced mathematics)	4 (calculus)

Table 1. Curriculum analysis

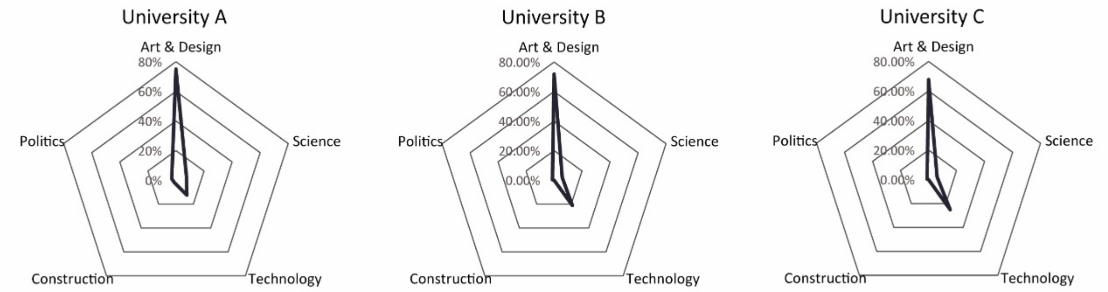


Figure 9. Focusing orientation of three top universities.

As mentioned above, China's urbanisation process has gone into another new stage, one crucial feature of which is the exploding boundary of the construction industry with the emerging technologies. The magnitude number of architects' career switching and our investigation on school teaching identify that the current education system does not really follow the social change, though they were deliberately claimed in missions. Therefore, we propose three steps to strengthen the curriculum in schools to make them fit the market demands now and in future.

Add new contents for architects' new roles

The social identity of an architect in this world has been totally changed. Architects were the minority group who grasped the drawing method of perspective in the fifteenth and sixteenth centuries. This scarcity made them respectable during that Renaissance Period. However, comparing with current emerging technologies like Big Data, Artificial Intelligence, and Genetic Technology, architecture designing is a skill with a very low technical threshold. Therefore, it is not strange that architects are gradually losing their prestige in the society. In this circumstance, the most crucial challenge of architectural education is not choosing the direction between globalism and localism (Tzonis, 2014), but combining those cutting-edge technologies with architecture design. Demarcating the boundary of education, incorporating newly developed technologies should be the first step to improve the education quality. Incorporating these new technologies or orientations is not only for increasing the employment opportunities but also is in line with the nature of architecture. Architecture as a discipline has not had a tightly fixed boundary since it was born and is of relevance to a significantly great number of different fields as time changes. Prue Chiles, the head of Sheffield School of Architecture, also stressed that future architecture students need to be educated in a broad context in order to function effectively in a multidisciplinary and expanding field (Design Buildings WIKI, 2014).

In accordance with those new roles of architects, some new courses and orientations have been explored in other countries and some of them have made a success. For example, many British architecture graduates have started playing a role in movie making because their digital animation and design skills learned in schools helped them break into the film industry (Shaw, 2015). Former architect Kibwe Tavares, the co-founder of an innovative studio, is exploring ways architects can use digital representation to encourage imaginative thinking through a combination of architecture and film (archdaily, 2016). Architectural education organisations in the UK have realised this new orientation and let Tavares's studio became one part of series seminars held by the RIBA (archdaily, 2016). On the contrary, scene design in video games, a kind of virtual architecture design which has a lack of people in China (Xinhuanet, 2006), still has not been known by architecture educators.

On the other side, Chinese architects can get easier access to their own business now. The Ministry of Housing and Urban-Rural Development of China updated their regulation on the management construction design business. One company can get the certification for starting businesses with only one Licensed Architect, rather than three 1st level Licensed Architects which were required before. This means that more architects will not only be required to be a designer, but also an entrepreneur. More knowledge of business and management need to be offered during college life. How to organically integrate this new knowledge with education activities on designing is another topic for future.

Remove unnecessary parts

There is a voice always criticising the lack of human science and art courses in architecture education and it becomes an entrenched preconception for many architectural educators (Coleman, 2010; Salama & Noschis, 2002). As a result, current architectural education is always intersecting with urban planning and landscape design, or other subjects more artistic or social science oriented. Although our survey indicated aesthetic ability as the most beneficial and satisfied part of the architectural education, it does not mean putting too many art or humanity courses in the curriculum is necessary.

Art and human science are important for architects, however, many of them are out of date and not suitable for being included in the curriculum. For instance, "Critical Regionalism" is an architectural theory trend which fights against the modern architecture lacking the identity of a place. Nevertheless, it actually should only exist in the beginning of globalisation when people were unsure whether they could retain their cultural identities while benefiting from globalisation, not now. Because globalisation already makes us similar and our new identity is the "global citizen": we wear the same style clothing, eat the same KFC and McDonald food, watch the same movies from Hollywood, use the same iPhone. Neither will architecture burden the duty of identifying unique cultural characteristics. Just like the Apple company will never produce the iPhone with culture features, only the performance (energy-saving, indoor environment quality, etc.) will determine the building shape in future (Zhao, Lavagna, & Angelis, 2016), rather than the culture.

Moreover, buildings are becoming increasingly expression-less rather than something carrying on architects' personal aesthetics or emotional preference, and architects with the strong individual features are fading out from the field. Most projects in industry require less and less artistic perception and are treated as a production rather than an artistic creation. Housing community planning, which is the main income source for design companies, can be a good representative case. In most occasions designing a residential community, the initial two things that need to be considered are "floor area ratio" and "sunshine hours on winter solstice day". "Floor area ratio" means the land intensity should be maximised to make economic profits for clients. Sunshine hours are required by authorities, to assure at least one room has one-hour sunshine on that day with the worst condition. These two objectives actually are in a trade-off relationship and should be balanced simultaneously, more related to math. Nonetheless, fresh graduates are unable to solve such basic design problems, but always trying to display their own "creative or artistic ideas".

Ultimately, arts are totally not crash courses which can be taught in one or two semesters. The art appreciation ability can be achieved only after years of nurturing. In some cases, due to the talent issue, even enough time may not bring satisfactory results. Hence, teaching results of arts in the architectural education totally cannot be guaranteed. Meanwhile, social science, which has a lower threshold for understanding compared with mathematics and physics, is not difficult to learn by students themselves. In conclusion, authors of this paper agree on the importance of art and human science, however, we also consider that they should be learned outside the education programme, not be something snatching the limited time from new technology and science learning. The purist of “art-based design” should be decreased and the attention on “technology-based design” ought to be raised.

Train self-learning skills

Pursuing architectural knowledge and improving design skills is a lifelong process. Therefore, we should teach rules for the changing of rules, teach knowledge required to obtain specific knowledge for a particular project (Rittel, 1971). Design by nature is giving a response to the present and finding its most valuable tools for the future (Bermudez, 1995). The future is not only an extrapolation of the past but a non-linear evolutionary leap difficult to be predicted. Hence, a vision of future is an initial necessity to help us revamp the architectural education. Bermudez (1995) deemed that

“paying attention to the future means at least two things for architectural education: (1) Look at the architectural discipline without relating our current curriculum. We should not let the existing education system restrict our imagination for the future. (2) Look at the architecture education with the frame of a curriculum. Too much discussion about future is theoretical without any permeation into actual teaching.”

Not only for their future, self-learning skills which suit the curriculum flexibility are also helpful for study at school. It is crucial to teach students how to learn rather than filling everything in their brains. To achieve this goal, educating students to become architects involves more than just inculcating the knowledge, skills, and abilities (learning outcomes) reified in courses (Webster, 2008). Meanwhile, the flexibility in design instruction (Hisarligil, Lokce, & Turan, 2013) and curriculum necessitates self-learning skills that make students adaptive and responsive to the ever-changing design industry.

Conclusions

According to the official website of China Higher Education (CHSI, n.d.), until the end of the year 2016, there were 290 Chinese universities running the major of architecture and the deduced number of graduates from this major is around 16000-18000 each year. However, such a huge education scale reinforces the future risk because the job market becomes not as prosperous as before and will be worse.

The online survey confirmed a trend that more architects are switching the career to a more technical orientation because of more opportunities there. Restructuring the curriculum is imperative to prevent poor employment of architects in the future. China has official education quality assessment on the architecture major (Ministry of Housing and Urban-Rural Development, 2016), however, this evaluation system does not have an articulate standard on

curriculum evaluation. It does not have a function leading good universities to be better but only can give an aim to the unqualified universities.
In the second part of this paper, knowledge boundary was analysed and curricula from three top universities were investigated. The authors proposed three suggestions to revise the curriculum: new technology-based design should be added; art and human science courses should be reduced; the learning skills to satisfy a long-lasting career life should be increased. The present paper is just a start to offer the insight on the problem and further research will go on being conducted.

Acknowledgments

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References

ARCHCOLLEGE. (2016). UA欠薪事件是怎么回事[UA International Arrear the wage]. Retrieved from http://www.archcollege.com/archcollege/2016/02/24362.html

archdaily. (2016). Visual Storytelling, Architecture & Animation. Retrieved from http://www.archdaily.com/779801/visual-storytelling-architecture-and-animation

Ball, S. (2004). Expanding the Role of the Architect. In B. Bell (Ed.), *Good Design: Community Service Through Architecture* (p. 133). New York: Princeton Architectural Press.

Bermudez, J. (1995). *The Future in Architectural Educatio University of Utah*.

Charalambous, N., & Christou, N. (2016). Re-adjusting the Objectives of Architectural Education. *Procedia - Social and Behavioral Sciences*, *228*(June), 375–382. https://doi.org/10.1016/j.sbspro.2016.07.056

CHSI. (n.d.). 建筑学[Architecture]. Retrieved from http://gaokao.chsi.com.cn/zyk/zybk/specialityDetail.action

Coleman, N. (2010). The limits of professional architectural education. *International Journal of Art and Design Education*, *29*(2), 200–212. https://doi.org/10.1111/j.1476-8070.2010.01643.x

Cuff, D. (1992). *Architecture: The Story of Practice* (1st ed.). MIT Press.

Design Buildings WIKI. (2014). The future of architectural education. Retrieved from https://www.designingbuildings.co.uk/wiki/The_future_of_architectural_education

Hisarligil, B. B., Lokce, S., & Turan, O. (2013). *MIMED Forum IV: Flexibility in Architectural Education*. Newcastle: Cambridge Scholars Publishing.

Jann, M. (2010). Revamping architectural education: Ethics, social service, and innovation. *International Journal of Arts and Sciences*, *3*(8), 45–89.

Mahalingam, G. (2007). *On deciding the boundaries of architectural knowledge*. Retrieved from https://www.ndsu.edu/fileadmin/mahaling/Architectural_Knowledge.pdf

Ministry of Housing and Urban-Rural Development. (2016). *建筑学专业评估通过学校和有效期情况统计表[Survey of Architecture Education Assessment by School and Expenditure]*. Retrieved from http://www.mohurd.gov.cn/jsrc/zypg/201606/t20160612_227744.html

Rittel, H. (1971). Some Principles for the Design of an Educational System for Design. *Journal of Architectural Education*, *25*(1), 16–27.

Salama, A., & Noschis, K. (2002). Introduction: An Architectural Education Responsive to Contemporary Societies. In *Architectural Education Today* (pp. 9–14). Lausanne: Architecture & Behaviour Colloquia.

Shaw, D. (2015). The architects using animation skills to build film careers. Retrieved from http://www.bbc.com/news/business-33757862

speiyou. (2013). *中国理科基础教育白皮书[White paper on basic science education in China]*. Retrieved from http://learning.sohu.com/s2013/xueersi/

Tzonis, A. (2014). Architectural education at the crossroads. *Frontiers of Architectural Research*, *3*(1), 76–78. https://doi.org/10.1016/j.foar.2014.01.001

Webster, H. (2008). Architectural Education after Schön : Cracks , Blurs , Boundaries and Beyond We ' re All Reflective Practitioners Now. *Journal for Education in the Built Environment ISSN:*, *3*(2), 63–74.

Wikipedia. (2015). 建筑老八校 [Top eight universities in architectural education]. Retrieved from https://zh.wikipedia.org/wiki/建筑老八校

xinhuanet. (2006). 高薪难求游戏设计高手 [Difficult to find game designers]. Retrieved from http://news.xinhuanet.com/employment/2006-07/13/content_4827325.htm

Zhao, S., Lavagna, M., & Angelis, E. De. (2016). The role of Life Cycle Assessment (LCA) and energy efficiency optimization during the early stage of building design. In *Atti del XI Convegno della Rete Italiana LCA Resource Efficiency e Sustainable Development Goals: il ruolo del Life Cycle Thinking* (pp. 554–563).

Design and Technology Education: An International Journal

23.1

Outreach programmes using the Triple Helix model to encourage interest in Science and Technology among underrepresented youth

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Abstract

Science and Technology entrepreneurship is one of the requirements of the new millennium, an era called digital society and globalization. Entrepreneurship is considered an agent of growth, wealth creation and development of society. Although New Zealand has experienced a rapid growth of education and research in Science and Technology areas, the country continues to face challenges in engaging communities such as Māori and Pasifika school students. There is a lack of understanding about career pathway choices and opportunities by parents and high school students, especially in these communities (Ministry of Business, 2014). A significant part of enhancing this understanding is building a relationship between the communities, science and technology industry partners and school students.

This paper presents an initiative taken by the university, government and community partners to create a better understanding of science, technology, engineering and mathematics (STEM) and entrepreneurship. The programme brought together business, government, researchers, school students, and the wider community within the Auckland region. It demonstrated the application of the triple helix model (Figure 2) to connect the three major players through STEM subjects and entrepreneurship. The programme encourages students to think about themselves as job makers rather than job takers in the future. A range of measures are used to evaluate its success, and initial results are presented. The format of this study can serve as a guideline for future initiatives aimed to improve students' awareness of STEM and entrepreneurship careers.

Key words

STEM; Entrepreneurship; New Zealand; Triple Helix Model; Māori and Pasifika.

Introduction

Science and Technology entrepreneurship plays a vital role in the growth and development of the economy and society. Science, technology, engineering and mathematics (STEM) is critical for enhancing living standards through economic growth and improving social and environmental outcomes. This can be possible when the government works closely with communities in designing educational policies and initiatives that can lead to job creation and self-reliance.

To lay a strong foundation for future generations and the 21st century economy, educators and decision makers must continue to promote STEM education opportunities. With the shift in demographics to include more diverse populations, we must realise the need to establish a good and supportive system for underrepresented segments of society. They contribute to future growth, so we must recognize the economic impact of not moving in this direction. Many of the western countries have recognised the importance of diverse and underrepresented communities and believe that inclusion through collaborations and considerations of social and cultural aspects is paramount (Figueroa, 2015). However, there are still gaps that separate underrepresented communities from the mainstream who are able to take advantage of the technology and STEM education and opportunities that exist in areas such as education, employment and health (Alam & Imran, 2015). Research also shows that barriers such as social esteem, financial status and culture can incite data disjuncture and a failure to adopt and embrace innovation (Lu, Meng, Guo, & Huang, 2013).

New Zealanders are known for their 'do it yourself (DIY)' and can-do attitudes towards problem solving and career planning. Youth need more support and guidance to engage in key areas of STEM subjects now and in the future (Ministry of Business, Innovation and Employment, 2014), especially Māori and Pasifika (indigenous and minority communities in New Zealand- NZ). In recent years, the NZ government has designed and supported initiatives to encourage and promote STEM subjects through the Ministry of Business, Innovation and Employment (MBIE), Ministry of Education (MOE) and the City of Manukau Education Trust (COMET) Auckland. They are funding educational projects in collaboration with universities and communities. This reflects an excellent example of a triple helix model used to promote STEM education, by bringing together business, government, researchers, students, and the wider community. This paper presents one such government initiative, called Unlocking Curious Minds by the MBIE to promote STEM education among school students, Auckland University of Technology (AUT), Māori and Pasifika communities and South Auckland schools and colleges. This article explores the best way to connect with underrepresented communities in the STEM area. The article outlines various approaches used to connect with the Māori and Pasifika communities, workshop activities with school students, and presents the outcomes. This study can serve as a guide for future initiatives to engage with underrepresented communities in order to improve students' interests in STEM and entrepreneurship. The article provides an overview landscape of NZ's underrepresented communities in STEM and also presents an initiative taken by the university, government and community partners to create a better understanding of STEM and entrepreneurship.

Engaging with Underrepresented Communities and Technology

The last 30 years of research involving technology, especially in STEM fields, has demonstrated some significant differences in gender and race among the participants (Charleston, George, Jackson, Berhanu, & Amechi, 2014). Statistics have shown that not all diverse and indigenous groups experience the same level of quality of participation in STEM across the world (Alam & Imran, 2015). Differences in culture, language, education level, age, socio-economic conditions, learning styles, communication style, family values and other factors influence the adoption of technology (Alam & Imran, 2015; Bianco, Cunningham, & McCombe, 2009; Helsper, 2008). Various scholars and practitioners have also identified similar gaps that influences the educational process of indigenous communities (Nakpodia, 2010, Gumbo, 2015). Although representation is improving, there are still gaps in the research regarding students from underrepresented communities in STEM.

It is important to integrate and encourage underrepresented communities to be part of the mainstream technology and STEM field. Modern information and communication technologies can have a positive impact on an individual's social inclusion and on the community's collective social capital as it continues to expand potential social networks and sense of belonging (Broadbent & Papadopoulos, 2013). Without access and participation, communities run the risk of remaining excluded from the mainstream and subsequently failing to integrate in society for the economic growth of the host country. The article highlights the role of technology and its important role in unrepresented communities for creating a sense of belongingness and integration in the mainstream.

Studies have showed that students discontinue their studies in STEM because of the barriers they experience in their educational journey (Long & Mejia, 2016). Some of the barriers include negative stereotypes about underrepresented minorities, educational institution barriers, racial discrimination, financial burden, lack of role models, limited numbers of mentors and insufficient support from the same race peers and faculty (Covington, Chavis, & Perry, 2017; Figueroa, 2015). Due to the family pressure, students from underserved groups often enter careers where career prospects are more obvious, stable and more easily understood by other family members (Hrabowski, 2011). Students from underrepresented communities can be adversely affected by institutional barriers as well. Many undergraduate engineering programmes also have lengthy or have rigid course requirements, restrictive admission policies and high entry costs (Long & Mejia, 2016).

A strong emphasis has been placed on increasing participation in technology and STEM areas among underrepresented populations. Even though STEM-related jobs are a growing sector of the New Zealand economy, participation from underrepresented communities are limited. Despite many initiatives to encouraging children to think and increase participation in STEM, the numbers are still limited (Ministry of Business, Innovation and Employment, 2014).

The New Zealand Context

New Zealand is a small, geographically isolated and well-educated country. Over 94 percent of the businesses are Small and Medium-sized Enterprises (SMEs). To overcome the disadvantage of the modest size and low level of large scale industries, they must continue to maximise opportunities to harness and cultivate our ability to be competitive and innovative. The current and future generations must be skilled in technology to develop new high-value products, meet the demands of business, and mitigate and adapt to the challenges of a quickly changing world (Ministry of Business, Innovation and Employment, 2014). This puts special emphasis on future generations to educate and create a platform to meet challenges and compete on the global scale.

Apart from the size of the country, New Zealand has a very diverse population. New Zealand's population is a multi-cultural, heterogeneous group comprised of people who speak different languages and have different values. Pasifika people are those who migrated to New Zealand from the Pacific Islands and who identify themselves with the islands or cultures of Samoa, Cook Islands, Tonga, Niue, Tokelau, Fiji, Solomon Islands and other mixed heritages (Gilbert & Bull, 2013). At the same time, a declining number of skilled workers in technology fields threaten New Zealand's global competitiveness and economic growth. Low participation, representation, engagement, and inclusion continue to also reduces the intellectual capacity of the New Zealand STEM workforce.

The socio-cultural deprivation belief prevails among school and tertiary students. This point of view suits the causality clarification of imperialism and its inheritance of social and economic predominance and subordination as a key supporter of negative social belief for Māori and Pacific Islanders, including low educational accomplishment (Bishop, 2003). The deficit lens assumes that students and their families are simply not adequately prepared for higher education. This may be due to their position of family resources, lack of role models or lack of value for technology-based education.

The government in New Zealand is concerned about the decreasing number of students in STEM education (Freeman, Marginson, & Tyler, 2015). The rapid growth of these communities and increasing numbers of youth entering the work force in coming years make it vital to address these issues. Schools, colleges and universities are seeking to increase the participation of Māori and Pasifika in STEM education (The Office of Ethnic Communities, 2016).

The pursuit of STEM to drive economic growth has seen a shift in the alignment of Government agencies from single, small policy agencies such as the Ministry of Research, Science and Technology, to the creation of the Ministry of Business, Innovation and Employment (MBIE), which brings together science and innovation, economic development, immigration, consumer affairs, building and housing. The mandate of this super-Ministry is to 'be a catalyst for a high-performing economy to ensure New Zealand's lasting prosperity and well-being' (Buntting, Jones, McKinley 2015, P. 22).

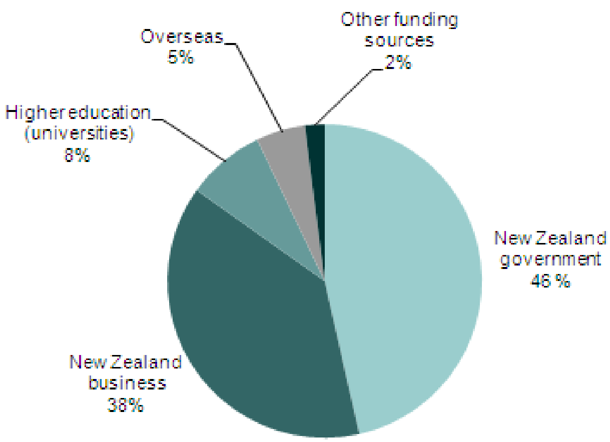

Figure 1. Research and development expenditure by source of funds (Buntting, Jones, McKinley, 2015)

As seen in Figure 1, New Zealand's expenditure on research and development as a proportion of GDP increased from 1.15% in 2002 to 1.3% in 2010, or a total of NZ$ 2.4 billion. Nearly half of this (46%) was contributed by Government. The Government is focusing on aligning its science funding more with business, community and future national needs. In spite of various initiatives and programmes, the attitudes and engagement of school and college students towards STEM subjects is much less when compared to international counterparts (Buntting, Jones, & McKinley, 2015). This is more prominent in Māori and Pasifika students. Students choosing whether or not to pursue science at their senior school or college is influenced by a variety of factors including students' experiences of learning science in and out of school, their personal interests and family background, knowledge about the range of study and career options that involve science, and possibly mathematics learning experiences.

Research Aim

The aim of this research was based on approaches to include underrepresented students and plan activities that would help enhance their aspirations towards STEM studies and careers. Firstly, the study sought to find out how best to involve students from schools where STEM study was not their first choice. Secondly, how to engage students in a way that was relevant to their backgrounds. The next section provides a brief role of the triple helix approach used to engage and encourage STEM subjects among underrepresented communities. It also discusses some of the initiatives by New Zealand Government's outreach programmes to encourage STEM among Māori and Pacifika communities.

The Triple Helix Approach to Outreach Programmes

The Triple Helix model of working between university, industry and government is a means of enhancing the knowledge based economy (Ministry of Business, Innovation and Employment, 2014). As knowledge has become an ever more important and crucial part of innovation, universities, as institutions for the generation and dissemination of scientific and technological knowledge play a critical role in generating innovators and problem solvers.

According Etzkowitz and Ranga (2008), the evolutionary process in the Triple Helix system involves a transition from the 'statist' stage in which government controls academia and industry, to the laissez-faire state relationship between the three institutional spheres; and finally to the hybrid stage in which each institutional sphere keeps its own distinctive characteristics, and at the same time assumes the role of the others. The evolutionary process underlying the Triple Helix system is graphically depicted in Figure 2 below. Each helix is connected to another, thus assisting in the formation of interfaces between them. Industry gains some of the values of the university, sharing as well as protecting knowledge; research groups in industry would collaborate with public and university research groups to achieve common long-term strategic goals (Etzkowitz & Leydesdorff, 1995).

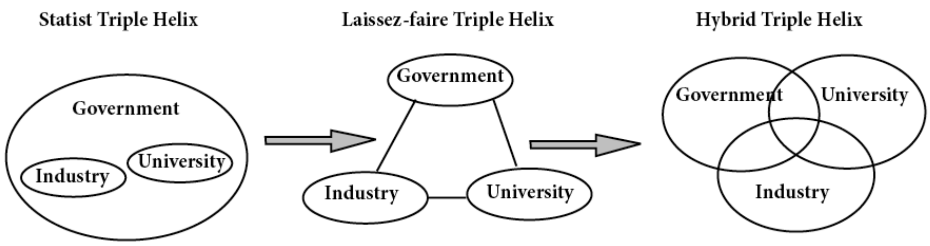

Figure 2: Hybrid Triple Helix Model (Abdrazak & Saad, 2007)

The Triple helix framework has been successfully implemented by business disciplines and many social enterprise projects. Recently, there has been some progress in engaging and encouraging a collaborative approach, evidenced in conferences and summits bringing together community leaders, educators and local and central government to develop strategies to improve opportunities and outcomes for indigenous people in STEM education and careers (Figueroa, 2013; Paige, Hattam, Rigney, Osborne, & Morrison, 2016). In this programme, we are using the triple helix framework to engage and encourage STEM subjects among underrepresented communities. Under this programme, partnerships were formed between government represented by MBIE, universities represented by Auckland

University of Technology (AUT) and community (schools and colleges). This programme is an initiative by MBIE under the banner of Unlocking Curious Minds. MBIE provided funding for conducting the programme, AUT conducted the programme in South Auckland campus and as a school and colleges from South Auckland served as a community partners for promoting and encouraging participation among their students.

The Unlocking Curious Minds is a contestable fund that supports innovative projects that excite and engage New Zealanders, particularly young people (aged 18 years and under), who have fewer opportunities to be involved with science and technology. The objective of the fund is to support projects that use innovative and/or best-practice approaches to provide New Zealanders with more opportunities to learn about and engage with science and technology, by MBIE:

- funding education and community outreach initiatives that focus on science and technology
- broadening participants' ability to engage with science and technology
- promoting the relevance of science and technology in their lives, and
- supporting them to engage in societal debate about science and technology issues facing the country.

The details of one such project, STEMpreneurial Bugs, and its outcomes and recommendations are discussed in the next section.

Method

Project Context

The main aim of the STEMpreneurial Bugs programme was to create a broader understanding of STEM by the youth of South Auckland, and link STEM to entrepreneurship. A significant part of this understanding is building a relationship and better engagement between the community, STEM industries and the youth of South Auckland region. A number of community-based science projects with local industries were developed, with involvement from South Auckland youth, university staff and students.

South Auckland is rich in culture and diversity and has a youthful population. Traditional systematic tertiary learning environment does not always connect well with such students who may learn better through doing. One of the strategies that supports education engagement is through informal hands-on workshops and interactive collaborations. Research into the low engagement of Māori and Pasifika students in STEM areas also identified a lack of understanding about career pathway choices.

The project extended the STEM "meet-up" programme based on the previous year's pilot programme. It developed a community of interest and provided ongoing support to high school students from South Auckland to pursue science education and the possibilities of establishing start-ups in STEM areas. This was done with a series of hands-on workshops and inspirational seminars run by enthusiastic scientists, technologists and entrepreneurs in STEM fields (referred to as STEMpreneurs).

Project Implementation

The age group in all workshops was 13-18 years with an average age of 15 years; with about equal proportion of male and female participants; over 90% of participant were Māori and Pasifika; all of whom are from South Auckland schools. Students from schools in low socio-economic areas were invited to be involved in STEMpreneurial Bugs programme. These schools have a higher number of students from Māori and Pacifika communities. Parents and family members also attended and participated in some of the workshops, and watched the students. We had industry speakers and community leaders in each workshop who have started a STEM start-up company, to share their experiences and inspire the youth.

To understand and capture the context of the workshops and interaction of the participations in the workshop, an observational study method was used for data collection. It provided an opportunity to observe what students do in the workshops, their level of involvement and to capture participants' enthusiasm in the workshops. As the participants were students, there were possibilities that they may have been unwilling to discuss in an interview setting. Data was collected from all the workshops by a passive observer. It helped the researchers to understand the students' level of participation and interaction and provided clues to future interest in technology and STEM areas. Data for this paper was gathered as part of workshop activities and informal feedback provided by the participants. The workshops were meant to transform traditional classrooms from a teacher-centred instruction into inquiry-based, problem solving, discovery zones where participants engage with the content.

In all the workshops, STEM subjects were connected with entrepreneurship, and students were encouraged to think about themselves as job creators. Six STEMpreneurial workshops were run and involved technology practice through engineering designing, building and testing. Participants built wave machines using jelly beans; saw demonstrations of flying quad-copters; and designed fabric sensors using wearable technology sensors and circuits. A number of engineering alumni and passionate speakers from industry, who had successfully established their own STEM start-ups were invited as guest speakers. They acted as role models and shared their own experiences and ways to create start-ups.

The six seminar sessions were run for groups of approximately 50 young people, along with many of their parents. School teachers were also welcome to attend, along with representatives from local businesses relevant to the topic of the seminar. Around 100 people were in the audience for each presentation. This wide community engagement is important to build awareness and community interest in STEM related careers.

The workshops involved hands-on activities and physical making of prototypes (Table 1). The students formed teams of three or four and were given project briefs to work through together, after a brief introduction to the topic. The activities involved in the workshops were normal conventional engineering education, but connection was made to the indigenous cultures and social values (discussed in section 7). The engineering/ technology method of generating ideas, selecting a concept and making a simple prototype that addresses the project brief, was taught during the workshops.

Workshop examples	Tasks
Design a flying paper airplane	Design a paper airplane so it has the smoothest and longest flight.
Work with a wave machine	Build a wave machine using jelly beans, and investigate different behaviours of waves.
Puzzles Contest	Solve fun puzzles, surprising paradoxes and interactive devices in maths and statistics.
Simulation of the Monty Hall paradox	The Monty Hall statistics paradox was simulated using carton boxes instead of doors, and prizes of chocolates instead of goats and Ferrari. A computer simulation was demonstrated followed by good discussions.
Modelling the Solar System	Modelling distances in the Solar System using simple materials on the desks and floor.
Fabric sensors	Building circuits that can be used in designing sensitive fabrics or touch sensitive buttons. This is usually used in health science and for designing sports outfits.
Simulation of biological evolution	Simulation of biological evolution using soft toys, string and plastic spoons.
Game design and development	Develop and set up rules for a game using playing cards and dice. Make modifications in the rules and analyse their impact.

Table 1. Workshop activities and Tasks

The environment was abuzz with support and guidance from university staff and tutors. The interactive projects offered compelling ways to engage young people by encouraging them to think of themselves as scientists and technologists or entrepreneurs in a positive and practical manner.

Project Outcomes

This STEMpreneurial Bugs project was undertaken in 2017 with youth in South Auckland, New Zealand. The project outcomes are presented in this section. The project’s aim was to create a broader understanding of STEM by the youth of South Auckland, and link STEM to entrepreneurship. Activities in the workshops were designed with an aim of enhancing the aspirations of underrepresented students towards STEM studies and careers. In addition, the workshops and seminars were open to a wider public audience, in order to involve a wider community.

Cultural and people issues were highlighted through getting the students to think about solutions that would be preferred by different communities. They were taught to create personas, i.e. profiles and descriptions of typical users from these communities. They were asked a number of questions during the maker events on why they chose a particular design, such as 'how a quad-copter can be useful to say farmers', or 'how sensors would be useful in a garment worn by the police'. These questions were deliberately open-ended in order to get students to think of various applications of technology, contexts of use and their utility to people in society. This helped the students to relate STEM to everyday applications and understand the benefits of technical innovations.

As part of data collection, informal feedback was collected from each workshop. In their informal feedback, all participating students answered "yes" to the two main questions: "Did you like the workshop?" and "Would you recommend it to your friends?" When asked if they would come again most of them said they would, and that they would tell their friends about it. In their responses to the question "What did you like most?" the vast majority reported that they enjoyed the sessions and learnt about 'interesting stuff'. The typical comments were:

"I loved the creative aspect";
"The practical activities";
"Getting to know more people and what's in the cloud";
"Both the presentations and activities";
"Lecturers, food, atmosphere";
"Becoming an entrepreneur";
"The new things we learnt and interacting with new people";
"The competitions";
"The puzzles";
"Mix and mingle and get to know more about maths";
"Everything – you fellows are awesome!"

The support staff noted the student interactions in their teams. Some students who were quiet at the start opened up and gave suggestions on how to put things together. Facilitators observed that some students had questions about the relevance of the applications of technology such as the fabric sensors.

Suggestions to engage under-served and indigenous students in Tech-Based Projects

The lack of participation among underrepresented communities in technology and STEM area must be solved not only through encouragement and engagement of students but also through policy and practice in educational institutions. Based on the observation data and informal feedback from all the workshops, some of the outcomes are listed below:

- Collaborate with communities has been a key ingredient in the growth and success of underrepresented students. Collaborating with local schools and colleges provided a wider exposure and increased number of participants in the workshops. This also helped to build a relationship with theSTEM department of schools for sharing knowledge and future projects.
- Encourage Māori values through design presentations and hands-on activities that fit within their traditions and contexts. For example, workshops were started by a Māori song and discussing cultural and spiritual aspects of education for creating a positive 'ahua' (to make in Māori) in the workshop. A sense of belongingness was introduced in the learning environment through whakapapa and whanau. In Maori, the whanau is the place where initial teaching and socialisation of things Maori took place. The individual was able to maintain their sense of belonging through their whakapapa or genealogical ties to of these structures in the society (Moeke-Pickering, 1996).
- Involving role models from their own communities can inspire and help students to see themselves in a positive future they can build. In our workshops, STEM entrepreneurs from the local community were invited to share their experience.
- Provide opportunities to connect STEM educators and their students with the broader STEM community and workforce especially from their own cultural background. Using the triple helix framework, our programme provided an opportunity for school teachers to connect with real world entrepreneurs and a tertiary environment.

Indigenous knowledge is enshrined in New Zealand's culture and legislation through the Treaty of Waitangi. Understanding Māori knowledge and cultural norms is essential for science practitioners in New Zealand if they are to build effective working relationships with Māori communities. To communicate and create educational values to Māori groups, scientists must first learn to engage with their values. Most of the workshops were based on Fonofale model, in which mental health is integrated with physical, spiritual and cultural beliefs (Crawley, Pulotu-Endemann, Utumpapu, & Stanley-Findlay, 1995). Crawledy et.al (1997) use the fale (house) as a metaphor with the family as its foundation and the roof representing the cultural values and beliefs that shelter the family.

- Provide projects that addressed real world challenges that can create an applied learning experience and help connect to their own cultural and social values.
- Involve young students in teams of three or four, so they have support from each other and learn from each other.
- Provide pathways for teachers to address diversity and become leaders in their

schools and colleges is also a key ingredient to attract diverse communities. One of the approaches could be to run on-campus education for teachers to equip themselves with the current knowledge in this rapid changing technology field. It supports teacher collaboration and fosters relationships that allow teachers to learn from one another.

Conclusions

The paper presents a programme of STEM outreach in collaboration with high school youth in underserved regions and university staff. The programme was designed to expose students to STEM subjects in an engaging format, and providing information on potential career pathways. The triple helix model of working with industry, government and educators was applied in this programme. This is a well-known entrepreneurial model in business disciplines but not so common in Science and Technology education outreach programmes with industry partners.

Embedding the importance of valuing people and their cultural backgrounds, together with discussions on their practical solutions was an effective way to relate to a diverse community. Teaching technology, science and engineering by connecting it to peoples' values, ethics and cultural beliefs is critical in a global society. Similar importance has also been discussed by researchers and scholars working in this area (Nakpodia, 2010, Gumbo, 2015). It is hoped that this programme will be expanded to other parts of the country and made sustainable in the future. The active participation and feedback by partners in this programme was positive.

The basic philosophy of the programme was that by having students actively engaged in hands-on tasks in science and engineering, supported by staff, they would appreciate the link between the topics and everyday applications. The approach of involving community role-models, educators and government representatives (Triple helix model), in student team activities has proven successful through our study. The use of inclusive design activities appropriate to community backgrounds also helped in engaging young learners, as was observed during the workshops and reinforced in the feedback received from participants.

References

Abdrazak, A., & Saad, M. (2007). The Role of Universities in the Evolution of the Triple Helix Culture of innovation Network: The case of Malaysia. *International Journal of Technology Managment and Sustainable Development, 6*(3), 211-225.

Alam, K., & Imran, S. (2015). The digital divide and social inclusion among refugee migrants: A case in regional Australia. *Information Technology and People, 28*(2), 344-365.

Bianco, N. L., Cunningham, A., & McCombe, C. (2009). *New communities, emerging content : digital inclusion for minority language groups*

Bishop, R. (2003). Changing Power Relations in Education: Kaupapa Māori Messages for 'Mainstream. *Comparative Education, 39*(2), 221-238.

Broadbent, R., & Papadopoulos, T. (2013). Impact and Benefits of Digital Inclusion for Social Housing Residents. *Journal of Community Development, 44*(1), 55-67.

Buntting, C., Jones, A., & McKinley, L. (2015). Consultant Report Securing Austalia's Future STEM: Country Comparision: Australian Council of Learned Academies.

Charleston, L. J., George, P. L., Jackson, J. F. L., Berhanu, J., & Amechi, M. H. (2014). Navigating Underrepresented STEM Spaces: Experiences of Black Women in U.S. Computing Science Higher Education Programs Who Actualize Success. *Journal of Diversity in Higher education, 7*(3), 166-176.

Covington, M., Chavis, T., & Perry, A. (2017). A scholar-Practitioner Perspective to Promoting Minority Success in STEM. *Journal for Multicultural Education, 11*(2), 149-159.

Crawley, L., Pulotu-Endemann, F. K., Utumpapu, R. T., & Stanley-Findlay. (1995). *Strategic Directions for the Mental Health Services for Pacific Island People*: Ministry of Health.

Etzkowitz, H., & Leydesdorff, L. (1995). The Triple Helix--University-industry-government relations: A laboratory for knowledge based economic development. *Easst Review, 14*(1), 14-19.

Etzkowitz, H., & Ranga, M. (2008). A Triple Helix System for Knowledge-based Regional Development: From "Spheres" to "Spaces". *Journal of Innovation and Entrepreneurship*, 1-29.

Figueroa, T. (2013). *Underrepresented Racial and/or Ethnic Minority (URM) Graduate Students in STEM Disciplines: A Critical Approach to Understanding Graduate School Experiences and Obstacles to Degree Progression*: National Institute of General Medical Sciences.

Figueroa, T. (2015). *Underrepresented Racial/Ethnic Minority Graduate Students in Science, Technology, Engineering, and Math (STEM) Disciplines: A Cross Institutional Analysis of their Experiences*. University of California, Los Angeles.

Freeman, B., Marginson, S., & Tyler, R. (2015). New Zealand: Towards Inclusive STEm Education for all Students. In Routledge (Ed.), *The Age of STEM: Educational Policy and Practice Across the World on Science*

Gilbert, J., & Bull, A. (2013). Building a Future-Oriented Science Education System in New Zealand: How are we doing? *New Zealand Council for educational Research*.

Gumbo, M. T. (2015). Indigenous Technology in Technology Education Curricula and Teaching. In *The future of Technology*: Springer Science + Business Media.

Helsper, E. (2008). Digital inclusion: An analysis of social disadvantage and the information society. *Department for Communities and Local Government, London*.

Hrabowski, F. A. (2011). Boosting Minorities in Science. *Science, 331,* 125.

Long, L. L., & Mejia, J. A. (2016). Conversations about Diversity: Institutional Barriers for Underrepresented Engineering Students.

Lu, X., Meng, X., Guo, J., & Huang, W. (2013). Empirical Study on Impact of New Information Communication Technology on Digital Divides: Beijing and Shanghai Symposium conducted at the meeting of the International Conference on Information, Business and Education Technology Atlantis.

Ministry of Business Innovation and Employment. (2014). *A Nation of Curious Minds - A National Strategic Plan for Science in Society*.

Moeke-Pickering. (1996). *Maori Identity Within Whanau: A review of literature*. Hamilton: University of Waikato.

Abdrazak, A., & Saad, M. (2007). The Role of Universities in the Evolution of the Triple Helix Culture of innovation Network: The case of Malaysia. *International Journal of Technology Managment and Sustainable Development, 6*(3), 211-225.

Alam, K., & Imran, S. (2015). The digital divide and social inclusion among refugee migrants: A case in regional Australia. *Information Technology and People, 28*(2), 344-365.

Bianco, N. L., Cunningham, A., & McCombe, C. (2009). *New communities, emerging content : digital inclusion for minority language groups*

Bishop, R. (2003). Changing Power Relations in Education: Kaupapa Maori Messages for 'Mainstream. *Comparative Education, 39*(2), 221-238.

Broadbent, R., & Papadopoulos, T. (2013). Impact and Benefits of Digital Inclusion for Social Housing Residents. *Journal of Community Development, 44*(1), 55-67.

Charleston, L. J., George, P. L., Jackson, J. F. L., Berhanu, J., & Amechi, M. H. (2014). Navigating Underrepresented STEM Spaces: Experiences of Black Women in U.S. Computing Science Higher Education Programs Who Actualize Success. *Journal of Diversity in Higher education, 7*(3), 166-176.

Covington, M., Chavis, T., & Perry, A. (2017). A scholar-Practitioner Perspective to Promoting Minority Success in STEM. *Journal for Multicultural Education, 11*(2), 149-159.

Crawley, L., Pulotu-Endemann, F. K., Utumpapu, R. T., & Stanley-Findlay. (1995). *Strategic Directions for the Mental Health Services for Pacific Island People*: Ministry of Health.

Etzkowitz, H., & Leydesdorff, L. (1995). The Triple Helix--University-industry-government relations: A laboratory for knowledge based economic development. *Easst Review, 14*(1), 14-19.

Figueroa, T. (2013). *Underrepresented Racial and/or Ethnic Minority (URM) Graduate Students in STEM Disciplines: A Critical Approach to Understanding Graduate School Experiences and Obstacles to Degree Progression*: National Institute of General Medical Sciences.

Figueroa, T. (2015). *Underrepresented Racial/Ethnic Minority Graduate Students in Science, Technology, Engineering, and Math (STEM) Disciplines: A Cross Institutional Analysis of their Experiences*. University of California, Los Angeles.

Freeman, B., Marginson, S., & Tyler, R. (2015). New Zealand: Towards Inclusive STEm Education for all Students. In Routledge (Ed.), *The Age of STEM: Educational Policy and Practice Across the World on Science*

Gilbert, J., & Bull, A. (2013). Building a Future-Oriented Science Education System in New Zealand: How are we doing? *New Zealand Council for educational Research*.

Helsper, E. (2008). Digital inclusion: An analysis of social disadvantage and the information society. *Department for Communities and Local Government, London*.

Hrabowski, F. A. (2011). Boosting Minorities in Science. *Science, 331,* 125.

Long, L. L., & Mejia, J. A. (2016). Conversations about Diversity: Institutional Barriers for Underrepresented Engineering Students.

Lu, X., Meng, X., Guo, J., & Huang, W. (2013). Empirical Study on Impact of New Information Communication Technology on Digital Divides: Beijing and Shanghai Symposium conducted at the meeting of the International Conference on Information, Business and Education Technology Atlantis.

Ministry of Business, I. a. E. (2014). *A Nation of Curious Minds - A National Strategic Plan for Science in Society*.

Paige, K., Hattam, R., Rigney, L.-I., Osborne, S., & Morrison, A. (2016). *Strengthening Indigenous Participation and Practice in STEM: University Initiatives for Equity and Excellence*: University of South Australia.

Paige, K., Hattam, R., Rigney, L.-I., Osborne, S., & Morrison, A. (2016). *Strengthening Indigenous Participation and Practice in STEM: University Initiatives for Equity and Excellence*: University of South Australia.

The Office of Ethnic Communities, (2016). *Flourishing Ethnic Diversity; Thriving New Zealand*. Retrieved from http://ethniccommunities.govt.nz/story/flourishing-ethnic-diversity-thriving-new-zealand

Review
Art and Design Pedagogy in Higher Education: Knowledge, values and ambiguity in the creative curriculum

Orr, S. and Shreeve, A. (2018) Art and Design Pedagogy in Higher Education. Routledge Research in Education series, Abingdon, Routledge.
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Reviewed by: Derek Jones

"I am for richness of meaning rather than clarity of meaning." (p16)

This quote from Venturi's *Complexity and contradiction in architecture* (Venturi, 1984, p. 16) sprang to mind whilst reading Susan Orr and Alison Shreeve's new book *Art and design education practices*. This type of paradox is the constant subject of this book – complexities and contradictions that will be immediately familiar to anyone working in learning and teaching in art and design education in the UK. The books accessibility to what is a tangled and difficult topic is what makes it well worth a read if you are involved in art and design education in any capacity.

Art and design education practices considers the contemporary UK higher education landscape in art and design and presents an overview, providing some general characteristics and features identified by the authors. Both Susan Orr and Alison Shreeve have extensive knowledge and experience in this domain and the book clearly demonstrates this, using both their own research and teaching experience, as well as being well grounded in the wider literature.

The volume is divided into two main sections, the first considering the territories of, and the second presenting practices in, higher art and design education. Generally, the former deals with common theoretical paradigms in most art and design education approaches, and the latter turns to how such learning and teaching is practiced and made tangible. Between these two familiar anchors of theory and practice Orr and Shreeve present a series of discussions summarising current thinking, often demonstrating how interdependent the two are.

Part 1 begins with the main introduction, in which the metaphor of stickiness is introduced to hold the work together theoretically (more on this later). Chapter 2 considers knowledge in and knowing, with particular reference to a broad overview of what this means in a pedagogic sense. Chapter 3 explores meaning and value(s) which continually recur in art and design curricula and how these are (re)constructed in learning and teaching. Finally, Chapter 4 tries to address ambiguity and uncertainty in creative education and concludes that it is both of these things!

Part 2 continues in a similar tone with Chapter 5 on identity and engagement as part of the sticky curriculum – both in terms of student identity and its construction in art and design education but also that of the tutor. Chapter 6 outline common teaching practices and uses many of the ideas presented elsewhere in the book to place these in context. Chapter 7 presents an excellent treatment of the project – something that they note needs much more attention in research and scholarship. Chapter 8 looks in a bit more detail at some of the 'operational' parts of art and design education: process, product and person. Part 2, and the book as a whole, is brought together in Chapter 9 to draw conclusions, although I took much of this to be an invitation to continue the discussion rather than any firm conclusion.

From this last, you may infer that this was a book I thoroughly enjoyed reading and then giving thought to. The main structure of the book worked well and I found Part 2 to be a particularly considered, contextualised and well-researched set of readings. I read this as a design educator, tutor *and* practitioner and it made me think about all of those aspects of what I do.

Dealing with such a complex and encompassing territory does, however, mean that some sacrifices have to be made. Part 1 does suffer slightly from this in terms of introducing some very large concepts with their own bodies of knowledge: for example, creativity in education, theories of design epistemology, power relations, postcolonialism, and many more make an appearance. This must have meant some difficult choices for the authors to make and it was clear which topics they were more interested. But art and design education does not take place in a deterministic, top-down, declarative classroom where a simple set of inter-disciplinary topics exist. It is necessarily part of the whole within which its students mean to one day practice and anyone aware of current design PhD methodologies will understand the breadth of knowledge domains that contemporary design researchers make use of, work within, or even contribute to. It is, as the authors make very clear, a messy and well-distributed business.

For me, the real strength of this book was how it grounded itself. Art and design pedagogy may be messy and difficult and complex and paradoxical and contradictory and… but we still have to *do* something. Part 2 demonstrates how this takes place across a range of subjects, in a range of modes and how these interrelate to the ideas introduced in Part 1, as well as the values within the broader college of art and design in the UK. This interrelation of doing and theorising is one that will be immediately recognisable to any design teacher or practitioner.

This is (necessarily) a UK-centric book, very much grounded in the Western paradigm of the arts and art education traditions, as the authors make clear throughout, despite the international influence of the subject itself. The book touches briefly on issues of culture and curricula, as well as some issues in representation, visibility and postcolonialism and this felt an appropriate level of detail given the scope. But the focus on traditional, proximate studio modes did leave some gaps in the territory with respect to technology, distance education, and modern practice-based learning. Some discussion of these took place towards the end of the book but I felt that some further acknowledgement of these modes would have benefited the work in terms of generally supporting many of the ideas presented. In fact, ongoing research into virtual design studios allows us to compare alternative and traditional studios in ways that have not been possible until now. The sticky, messy, contradictory socius that is a traditional, proximate studio is just as important in a virtual one and many of the sticky concepts presented here are just as relevant.

Ambiguity, uncertainty, paradoxes and stickiness

Central to the book is the paradox of a subject that is both necessarily subjective but that also has to be objective in some particular ways. This, and many other dualities, are presented throughout. For example, assessing individuals … in groupwork (p73); the real world versus academic institution (p99); the learning expectation of unpredictable creative responses (p129); and, of course, the zen of teaching but not teaching, among many others.

Balancing the many paradoxes identified is presented as the business of both teachers and students in art and design. I did wonder why so much of this was framed as a series of dualities. Or that it is simply that we have to accept that it is complex or uncertain. Perhaps these are mainly second hand contradictions, passed on from practitioner to practitioner over time but I do think that the contemporary design teacher has to do better than that for all the reasons outlined in this book.

To help approach such paradoxes the authors introduce the concept of stickiness at the start of the book and return to it throughout. Early on they provide several characteristics of this conceptual gestalt to help orient readers. I have to confess that I found this difficult to begin with - the subject in itself is a sufficiently ill-defined problem that using a metaphor like this didn't (for me) add much. There may be something that binds art and design education but maybe, as they suggest in the book, this is not a traditionally representational idea.

What I did wonder was whether a design approach might be more appropriate here: for example, we might not know what the end result will be *specifically*, but under no circumstances does that mean that no progress can be made. The design process is strange blend of directional uncertainty and a common fallacy in the study of design epistemology is to consider uncertainty to be the same as ignorance. Knowing that something doesn't work is as important in finding possible solutions. Perhaps we need to be a bit more confident about how we use concepts such as uncertainty. For example, I have to admit that I found the 'teaching but not teaching' a difficult one to accept because it ignores the other major element here: learning. A good studio tutor flips between teaching and allowing space for learning and it doesn't necessarily need a contradiction to allow this to take place. Perhaps much of our thinking around these issues has been clouded by the tyranny of simplified dualities. Returning quickly to Venturi, it perhaps doesn't have to be 'either-or', we can have 'both-and' (Venturi, 1984). Good art and design schools and curricula have been providing 'both-and' for a long time and it is perhaps only now that we have the intra-disciplinary confidence to make stronger claims about what we do as a group of practitioners in both the subjects themselves and their teaching. I think we can tell richer stories about the complexities and contradictions in art and design education.

My impression of this book is that the authors intend this too: the moments that delighted were those where they really got down to the difficult, messy business of art and design pedagogy and really presented these confidently and unashamedly as part of the tradition and contemporary practice of art and design education. Shreeve and Orr show how concepts such as contradiction might be reframed in significantly positive and productive ways; where the balance between tensions is the perfect space within which design learning might take place. As examples, take away their summaries of ‘the opportunistic curriculum’ (p61); ‘productive ambiguity’ (p63); or simply their articulation of ‘the project’ (ch 7).

I have to confess that I wanted much more of this as I neared the end of the book….

Power

One of the most important tensions to arise from the central subject of uncertainty is that of power relationships. Most of the examples given in the book show positive examples of using uncertainty, paradox, ambiguity, etc. in supporting novice designers to learn. But these concepts can easily generate a far less positive outcome. The authors refer to the bad old days of studio education where power asymmetries arising from uncertainty were simply part of the pedagogy – students ‘learned’ what not to do and quickly adopted behaviours to suit, or they dropped out.

It is harder to imagine some of these practices taking place in contemporary art and design education but this does not mean that it’s no longer an issue. In fact, because such explicit power asymmetries are not in evidence, there may exist a range of other more implicit forms of imbalance, far harder to identify and address. With a side reference to student agency and socio-cultural backgrounds, the they quite rightly state, “We do not need, however, the obscured cultural practices which can serve to disadvantage some.” (p148). I do think this and others could have been considered further in places. If, at the heart of art and design pedagogy there lie intransigent paradoxes that require negotiation, then the central paradox is that this is necessarily an emerging (and changing) power asymmetry. Thus, it becomes the core business of teachers to be aware of this and practice with such an awareness. Whilst the book gives examples of tutors for whom this “…was an ideal which they aspired to” (p78), how problems arising from this may be addressed is less well covered and there were a few opportunities to refer to some excellent critical literature in this area.

The book, however, prefers to concentrate on good practice and giving examples of how such practice might be propagated as part of a community of practice and I can understand this from a practitioner’s point of view. For example, they note how effective the crit can be in terms of semi-public staff development: a negotiation of tutor beliefs and preferences. I can easily imagine this being taken much further as part of broader, collegiate approach.

And this is where, again, I think the book’s strength really lies – as an introduction to *more properly explore and develop* the difficult task of working in the grey area(s) of art and design higher education. The stark lesson suggested here is that, if we wish to maintain the blurriness of paradox in art and design education, we have to take seriously our responsibility for the how power is deployed, displayed and negotiated between all parties in such a context. These difficult topics and spaces of interpersonal learning are a welcome addition to the book and such discussions must become central elements in the praxis of art and design education. As a quick example, the authors refer to the sex/gender imbalances in Art and Design education, particularly in relation to expected gender congruence (p78). This is an example of a single, core, implicit bias that many of us hold, whether we wish to or not. But it is how we respond to such bias that usually makes the greatest difference:

gender equity, like art and design, is perhaps best practised regularly, not taught once and forgotten (Robertson et al., 2017).

Conclusion

In conclusion, this book presents a good overview of the current landscape of pedagogical practice in art and design education and its theoretical basis is drawn from that practice in and of itself. This situates it in its own knowledge domain and makes it far more approachable to both teachers and scholars in this area. Whilst I do think there are some areas that could have had more depth and detail, it captures well current practice and values. Unfortunately, it is priced at the 'University Library' end of the scale (£105 at the time of writing), which might limit its audience.

I'll end with the same approach I took in reading the book, as a design tutor, and ask: Was this useful? Did it make me think about my practice? Did it make me uncomfortable about some of my practice? Did it change my thinking? Did I keep coming back to some of the concepts at utterly inappropriate times of the day?

The answer to all of those was a definite yes. You can't really ask more than that: unspecified, but rich, personal learning outcome complete….

References

Orr, S. and Shreeve, A. (2018) *Art and Design Pedagogy in Higher Education*, 1st ed. Routledge Research in Education, Abingdon, Routledge.

Robertson, J., Williams, A., Jones, D., Isbel, L. and Loads, D. (eds.) (2017) *EqualBITE Gender Equality in Higher Education*, 1st ed. Rotterdam, Sense Publishers [Online]. Available at https://www.sensepublishers.com/catalogs/bookseries/other-books/equalbite/.

Venturi, R. (1984) *Complexity and Contradiction in Architecture (Museum of Modern Art Papers on Architecture)*, 2nd ed. New York, The Museum of Modern Art, New York.

Review

Design Epistemology and Curriculum Planning

Norman, E., & Baynes, K. (Eds.). (2017). *Design Epistemology and Curriculum Planning*. Leicestershire: Loughborough Design Press.

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Review by: Jeffrey Buckley, KTH Royal Institute of Technology, Sweden, Stockholm.

This fascinating book sets out to explore design epistemology in the context of curriculum planning and is a response to the Expert Panel which considered the future of Design and Technology (D&T) in the English National Curriculum. Ever since Aristotle proposed his intellectual virtues of epistêmê, technê and phronêsis, the concept of epistemology in education has invoked substantial philosophical debate. Much discourse pertains to the validity of knowledge types such as 'knowing that' and 'knowing how' (Hetherington, 2011; Stanley & Williamson, 2001) with further debate focussing on the role of knowledge in education relative to what are often described as transferable or 21st century skills or competencies. Part 1, the introduction to this book, eloquently frames design epistemology as "what designers know and how they know it" (p.6) and although not yet well understood relative to other ways of knowing, positions designerly ways of knowing as a critical construct in contemporary education.

Part 2 of the book contains an editorial from a 2013 issue of *Design and Technology Education: An International Journal* (Norman, 2013) which builds on the introduction in helping to frame a conception of design epistemology. Although specifically addressing design curriculum planning in England, the discussion is applicable to design curricula in general as Norman mediates the positions commonly taken in terms of design knowledge. The first of these being that the knowledge inherent in design is unbounded as design problems are undefinable prior to designing and the second is that there is a fixed core of knowledge allowing designing to take place. Referencing work from the Assessment of Performance Unit (APU) and Vincenti (1990), Norman manages to describe how neither of these positions are wholly accurate as design problems vary in how well- or ill-defined they are. Yet although this description complicates the idea of design epistemology, you are left with a greater tacit understanding of what a designerly way of knowing could mean.

Part 3 comprises of a series of six short chapters, each by a different author, which provide commentary on different topics related to design epistemology in education. While each chapter delivers an important message independent of the others, they are all tangibly related and through their compilation the effectiveness and compulsion of their ideas is magnified. In the first of these chapters Atkinson (pp. 13-17) highlights the effect that the fluid nature of design epistemology discussed in Part 2 can have on its position and perceived position in educational curricula. The Expert Panel considered D&T to have weaker epistemological roots and insufficient disciplinary coherence. Atkinson notes that while D&T is coherent in terms of its aim, it is less clear in its prescription of what should be taught and how it should be taught. She then progresses to describe the difficulty this can create for teachers in parallel to describing changes which have occurred in the provision of D&T both at post-primary level and in teacher education and culminates in how this can result in a negative spiralling effect in terms of the provision of D&T. This is followed up by a chapter discussing the thinking behind the Expert Panel when considering the importance of subjects for the English National Curriculum (Hardy, pp. 18-21). Hardy notes how the work of Hirsch (2006) and Willingham (2009), who focus on the value of knowledge and facts was lauded by the commissioners of the Expert Panels report. Unfortunately for D&T, where the boundary of knowledge is not clear, this resulted in its decline in the national curriculum.

Subsequently, Kierl (pp.22-27) navigates the reader back to discussion on the nature of design epistemology. While still acknowledging curriculum planning, Kierl comments on locating design knowledge. The chapter poses a thought-provoking, philosophical debate in which Kierl discusses orthodoxies of knowledge, subjects as knowledge disciplines, positivism, critical theory, knowledge interests and more to infer how a reframing of design epistemology could lead to an elevation of its richness and power as a field of learning. Newman (pp.28-31) maintains this discourse on design epistemology by discussing how designers know what they should know. A number of very important points are made. In the opening part of the chapter Newman describes how he can easily explain what he knows to other designers but to a non-design audience this is harder. The implication of this being that there is either a particular language to design, or that design knowledge is tacit and only through experience can it be innately understood. As the chapter progresses it is clear that Newman explicitly means the latter. Newman communicates some very fundamental messages about how design knowledge can be learned, but underneath his discussion is another facet of design which is a challenge to educational stakeholders – not only is design epistemology fluid, but many elements are tacit and some may only really be understood by other designers. Shepard (pp.32-38) talks specifically about design methodology. Similar to how design knowledge is a complex construct, Shepard discusses how this is the case with design methodology and the design process as well. While this chapter does give more concreteness to knowledge that is important for designers, its conclusion is significant in its portrayal of the broadness of design, that it does not and should not exist in isolation in the subject of D&T. The final chapter in Part 3 is offered by Spendlove (pp.39-42) who contributes a complex discussion on design thinking and presents the need for the D&T community to capitalise on the emergence of design thinking in education in the conceptualisation of a new "Design and Technology 2.0". Similar to previous chapters, Spendlove reflects on the ambiguous nature of design epistemology, the English governments' current educational position and the decline of D&T in post-primary education in England and in doing so his chapter has been perfectly placed to bookend much of the ideas and discussion from its predecessors. The vision of a Design and Technology 2.0 also offers a welcomed optimistic note through its provision of a collective agenda.

Part 4 contains two chapters both on visual thinking and graphicacy, the first by Baynes (pp.47-64) and the second by Danos (pp.64-84), which are preceded by a short introduction.

It is difficult to put a review of Baynes' chapter into words – trying to do so has become a somewhat meta experience. The reason for this is that Baynes' chapter consists predominantly of a delightful array of images. Created by Baynes himself, the images serve the purpose of illustrating how the human mind can make meaning out of visuals. The saying "a picture is worth 1000 words" is very appropriate for this chapter. The 12 images which are used reflect just how powerful graphics can be as a language or perhaps a metalanguage of design, a message which is made clearer and more efficiently through the use of the graphics themselves. Danos adds to this discussion by acknowledging the ubiquity of visuals in society and describing her own work which involved the creation of a taxonomy of graphicacy. Having established the educational and societal importance of graphicacy, Danos provides evidence of its natural development in children and of how it can be developed in education. Her synthesis of the human cognitive capacity to interpret visuals and the communicative power they can have with the societal and educational need to further acknowledge the development of graphicacy creates a strong narrative for its further consideration within D&T education.

Part 5 contains another contribution by Baynes (pp.85-92) in which he offers a wider perspective on design epistemology. The chapter offers an interesting perspective on design and in particular the value of design. An analogy involving a park is used to describe how design can offer a value which is difficult to quantify but that this characteristic does not mean it has no value. When reading this you are reminded of earlier discussions in the book and are forced to contemplate the question of how then do we prove the educational significance of design? In the conclusion, key aspects necessary to any design epistemology are presented as well as exemplars of how these can be translated into questions which can guide the development of a framework of design suitable for education.

Norman and Baynes (pp. 93-100) conclude the book with a single chapter in Part 6. They offer a clear and coherent overview of some of the points addressed in the previous chapters relative to the Expert Panels' review and conceptions of design epistemology. Clearly stating the aims of this book, they put forward an agenda to create a framework for design epistemology which is helpful to anyone in better understanding the nature of design, its human significance and its value. Finally, in an attempt to drive this agenda forward, they culminate on a number of pertinent key matters for discussion.
Overall, this book was very enjoyable to read. I read most of the chapters more than once and I envision that I will regularly refer to many of them in future discussions on knowledge in design education. The book will certainly provoke thought in terms of design epistemology. On one hand there is a clear need for the ill-defined nature of design in education and it is difficult to conceive of how this isn't a unanimously shared point of view. On the other hand, you can appreciate the difficulty that would exist in appraising the subject due to its insufficient "disciplinary coherence". This is a clear issue which needs to be addressed in some form, but reflecting on the discussion of the tacit nature of designerly knowledge it is clear this will ultimately look different to that of other subjects. Upon finishing the book I suspect most readers (at least those with an interest in D&T education) will be eager to engage in the seminars proposed in its concluding discussion.

References

Hetherington, S. (2011). *How to know: A practicalist conception of knowledge*. West Sussex, UK: Wiley & Sons.

Hirsch, E. (2006). *The knowledge deficit: Closing the shocking education gap for American children*. Boston: Houghton Mifflin Company.

Norman, E. (2013). Design epistemology and curriculum planning. *Design and Technology Education: An International Journal*, *18*(2), 3–5.

Stanley, J., & Williamson, T. (2001). Knowing how. *The Journal of Philosophy*, *98*(8), 411–444.

Vincenti, W. (1990). *What engineers know and how they know it: Analytical studies from aeronautical history*. Baltimore and London: The John Hopkins University Press.

Willingham, D. (2009). *Why don't students like school?: A cognitive scientist answers questions about how the mind works and what it means for the classroom*. New Jersey: John Wiley and Sons.