INNOVATION DESIGN ENGINEERING: NON-LINEAR PROGRESSIVE EDUCATION FOR DIVERSE INTAKES

Ashley HALL[1] **and Peter CHILDS**[2]
[1] Innovation Design Engineering, Royal College of Art
[2] Department of Mechanical Engineering, Imperial College London

ABSTRACT
This paper discusses the non-linear progressive educational techniques developed and adopted by the Innovation Design Engineering (IDE) masters degree at the Royal College of Art and Imperial College, London. In particular a focus is applied to the development of creative processes for diverse intakes without recourse to overt systems presentation. Innovation design engineering is viewed as a cutting-edge product design, experimentation and enterprise discipline with applicants drawn from three areas including engineering, industrial design and other art, design and business disciplines. The co-education of such a diverse intake requires careful balancing of an academic programme to ensure that all parties are stimulated and enabled to expand their knowledge and skills base while also contributing to a communal environment via team-based activities. Designers work at the centre of complex, demanding projects, juggling creatively in teams, to generate great ideas, designs and successful products. In order to achieve such goals it is critical for students to attain high levels of self-reflection, social networking, work-collaboration and interdisciplinarity. This is achieved by surrounding the students with experts and leaders in their fields to support them in their design ventures.
Through reflection and theorising, a conceptual base for educating innovative design engineers is explored. One of the techniques described provided evidence to suggest running a design enterprise strand in the programme, a proposal that has now been implemented. Students elect from three learning strands: experimental design; design for manufacture; and design enterprise. The design enterprise strand addresses product, idea and service launching, finance, marketing, commercialisation, designing service support infrastructures and establishing production and supplier relationships. Design for manufacture is the traditional core industrial design activity associated with advanced manufacturing, new markets, user centred design, aesthetics and technology innovation. Experimental design is a research driven rigorous approach to developing fundamental new industrial concepts, paradigms, technologies, designs and insights. The strands reflect the expanding scope of industrial design and hint at the generation of new sub-disciplines.

Keywords: Innovation design engineering, non-linear, diverse intakes, progressive education

1 NON-LINEARITY

To quote Sir Ken Robinson:

> '*Our education systems are dominated by linear assumptions of what will be relevant to the future, and frankly we don't know what will be relevant to the future. What we do know is that it won't be linear*.' [1]

One of Robinson's arguments in his address to Apple's 2008 education summit is that the linear nature of our education system fails to connect properly with our innate creative abilities and that we are failing to liberate individual talents. While it is easy to observe that industrial design courses are on the surface 'creative' (aesthetic and technical) the question remains as to how well that creativity fits both the individual and the continued expansion of what falls within the realm of industrial design practice. Following on from this its interesting to pause to consider the main (simplified) phases of industrial design education history.

The first phase that evolved from the early 20th century was the 'one size fits all' ideology which promoted one model of design process that was adaptable to all people, scales and outcomes. This mindset started to fade in the 1980's when 'issue-based' or specialised industrial design degrees started to emerge, such as product design futures and sustainable design. In the current phase we are incorporating a plurality of approaches within a single syllabus through recognising the diversity of natural creativity within student groups and the variety of ways they need to learn. This takes the form of pathways, strands and platforms. In addition we are moving from an industrial to a post industrial outlook where good quality design of industrial artefacts is commonplace and designers looking for new challenges are gravitating towards systems, experience design and design production. One of the linear mythologies inherent in industrial design is that students study a range of core modules, which they are then expected to 'assemble' in a final project to show mastery of their discipline.

In his 1989 doctoral dissertation Houghton [2] proposes a new model of educational enquiry based upon non-deterministic, chaotic and non-linear systems. His scope is aimed at long-term educational initiatives in science and the research model that drives education. The interest is in how these ideas can be applied at a smaller, course scale and to the education of industrial designers. A selection of the most relevant parts of Houghton's dissertation is as follows:

> '*At the classroom level, interaction has more than a positive effect, it is a pre-requisite for learning and the facilitation of higher-order thinking skills, and therefore stimulating greater depth of interaction is sought. These higher-order skills emphasize innovation and creativity which in turn promote indeterminism. The divergency inherent in innovation and creativity carries interesting parallels to the divergency inherent in the nonlinear system dynamics of deterministic chaos*.'

He goes on to propose the stifling of innovation by convergent models:

> '*The second hypothesis derived from the larger educational problem is motivated by the stifling of innovative practice and with the lack of timely adjustment of the educational system to changing social needs. Variance and thereby innovation is reduced through both explicit and implicit phenomena. A characteristic of educational systems is their fixed hierarchies with top-down control structures. Educational systems have largely moved towards certain designs for the purpose of achieving greater control and greater prediction*.'

And finally to consider the application of divergent systems to other educational models:

> '*Central to critiquing root assumptions is the examination of the alternatives to convergency, especially the divergency created by chaotic dynamics, and to examine the spread of its application to other disciplines and to consider its study and relevance to education.*'

Design courses have tended towards a convergent worldview encouraged by unified tutoring methods, implied narratives in programme structures and the presentation of over simplified design system models. The non-linear model creates a context for innovation via methods which are elicited from 'within' the student rather than imposed from without and delays the presentation of overt systems until students have a design model against which this can be tested and deliberately avoids convergent tutoring styles. In essence this is a paradigm shift from a linear convergent teaching model to a non-linear divergent one. These ideas are also discussed by Glanville [3] and Robinson [4] in his paper on classroom control.

2 UNIQUE CHALLENGES IN DESIGN & ENGINEERING

The challenge in educating both designers and engineers concurrently is that of bringing to the designer the discipline of analysis and technological mastery, whilst for the engineer it is the move from analysis and theory to the handling of grey data. To quote Nigel Cross:

'*they have learned to live with the fact that design is ambiguous*' [5]

Or, they *have to learn* to live with the fact that design is ambiguous. The challenge then is to incorporate a grey data handling facility into problem solving activity. On the ground this means a conscious decision to avoid presenting over simplified design models at an early stage. In order to achieve their objectives students require progression to heighten skill levels and understanding, but at the same time an avoidance of narrative is key to prevent over simplified and caricatured design solutions. The concept of a non-linear progressive model that exposes students to diverse experiences through modules, master classes and workshops aims to generate a reflective outlook. This outlook is encouraged with tutorials where a consideration of a student's own trajectory is articulated.

An important issue in such models is to assist students and staff in coping with cognitive dissonance [6]. In general, inconsistent actions and attitudes make us feel uncomfortable. This may be manifest in us seeking affirmation that a particular decision or approach is acceptable or suitable and avoiding anything that might prove a decision to be anything less than perfect and wise. This can drive us to unhelpful behaviour such as if an individual believes him or herself to be weak in a particular area then that individual may avoid any activity in that domain in case their weakness is identified. In the realm of thinking this may lead to the rejection of many ideas because the pain of dissonance overcomes any potential benefit from proposing the ideas. Progressive models need to enforce the value of inconsistent action and ambiguity in creative processes.

At this point it becomes worthwhile to examine the typical development phase of intake students. The engineer will be adding design to their arsenal, while the designer though initially appearing quite successful will realise after a while that their model is too constrained for the tasks that face them. This results in having to break, and then remake, a far more complex and sophisticated design-model. Students from other backgrounds will need to successfully add both design and an ability to work with technology through the growing of their entry core strength.

Students enter the IDE degree programme from one of the three main backgrounds: engineering; industrial design; and ‘other’. Engineering covers students from strong technical backgrounds including mechanical, electrical, aerospace and manufacturing engineering, computer science, materials science and physics. Typically people from this background solve problems via well known formulas, principles, algorithms and systems where the initial nature of a problem can be clearly described. Their challenge is to incorporate the ability to handle and be happy with grey data during a problem solving process, especially when dealing with ‘wicked’ problems [7] and ‘meta themes’. Essentially this means dealing with a contra-flow from certain principles of work to grey ambiguous data and back again. In essence the student ‘incorporates’ design into an existing technical skill set. A reflective design outlook encourages the asking of questions, whereas engineering encourages the search for answers. Industrial designers include product, furniture, 3d design and computer aided design. This profile contrasts via strong design and problem solving skills but a typically weaker understanding of fundamental principles and integrating technology at a conceptual level. The challenge here is to learn the integration of engineering and technology that in turn means the deconstruction and reconstruction of much more sophisticated design process. Students from ‘other’ backgrounds include architects, fine artists, sociologists, interior designers, business, MBAs, accounting and marketing etc. In this instance the entrants to the course already have strength in an area relating to the programme and the challenge lies in developing design and technology skills by building on the existing level of strength rather than starting at the beginning. The diversity of intake creates a situation where the input types are arranged through many levels of the Cross-Dreyfus matrix proposed by Dorst and Reymen [8] visualised here by the authors in Fig.1.

Cross Dreyfus Matrix

Cross Abilities: / Dreyfus Level:	Novice	Advanced beginner	Competent	Proficient	Expert	Master	Visionary	Intake Type:
Produce novel, unexpected solutions								Industrial Design
Tolerate uncertainty, working with incomplete information								Industrial Design
Apply imagination and constructive forethought to practical problems								Engineer
Use drawings and other modelling media as means of problem solving								Industrial / Engineer
Resolve ill-defined problems								Industrial
Adopt solution-focussing strategies								Engineer
Employ abductive/ productive/ appositional thinking								Industrial
Use non-verbal, graphic/spatial modelling media.								Industrial / Engineer

Figure 1. Cross-Dreyfus Matrix.

Typically an engineering graduate would score highly on the ‘adopt solution-focusing strategies’ and ‘apply imagination and constructive forethought to practical problems’, whereas an industrial designer would be expected to score highly on the ‘resolve ill defined problems’, ‘tolerate uncertainty when working with incomplete information’ (new ideas by their nature are uncertain and to innovate we need to tolerate ambiguity and keep minds open) and ‘producing novel unexpected solutions’. Both should have strengths in using non-verbal media and ‘use drawing and modelling media as a means of problem solving’. As can be observed in the heterogeneous pedagogic needs of the different input types which are at variance and hence necessitates the logic of a non-linear programme, which does not narrate progress across the board irrespective of background but generates a reflective attitude forming after certain time the insights that form the crossbar of an individual ‘T’ shaped skills profile.

3 ‘T’ SHAPED PEOPLE

In post-graduate education all candidates have an existing pillar of strength. Conventional logic is to extend and broaden this pillar at masters level to produce a depth and strength of skill to re-enter the world at a higher level. However when moving laterally to another discipline and in particular with creative disciplines we seek to produce graduates with a new shape. These people have an existing pillar of strength with a crossbar of interdisciplinary aptitude that creates a ‘T’ shaped person. Tom Kelley [9], general manager and founder of global design consultancy IDEO describes ‘T’ shaped people as the ideal employees in that they have a broad range of cross-disciplinary skills (speak many business-discipline languages) while at the same time possess a personal depth of expertise.

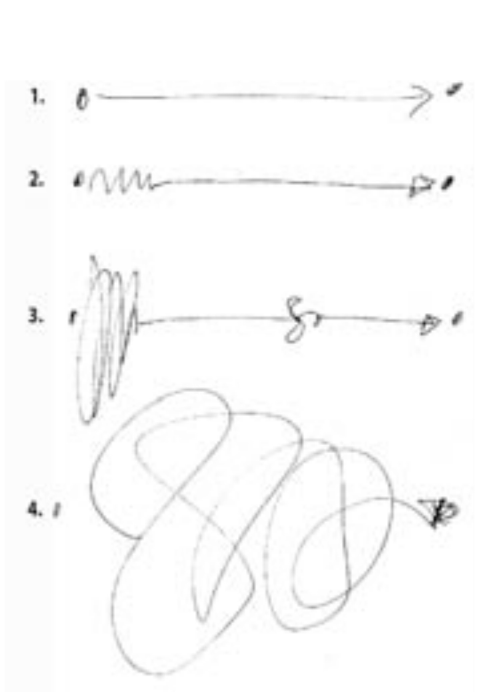
4 DIVERSE BACKGROUNDS

The Innovation Design Engineering course has moved away from its traditional base of educating engineers in design, to a one thirds mix of engineers, designers and candidates from other diverse backgrounds. The adoption of a wide entry profile has challenged the development of a new methodology for educating design students with widely differing educational needs.

The two examples cited below illustrate the changes in thinking that students undergo and further re-enforces the necessity of allowing the exploration and development of their own creative processes in response to innovation rich contexts. The following quotation from Innovation RCA Professor Jeremy Myerson is insightful in explaining the changing mindset of a first year student.

> “*I met a new IDE student who had been on the course about 6 weeks and I asked how things were going. He replied:*
> *‘Well, on my engineering degree I knew I had the right answer when everyone else had the same answer. On IDE I’ve realised I have the right answer when everyone has a different answer, but now…. I’ve started to realise that there may not be an answer’* [10]”

The sketches in Fig. 2 and the legend is further evidence that illustrates the changing outlook of a student who came from an accounting background and how their design thinking has developed.



Line 1: Thinking in the accounting profession. If any accountant sees this they will be very upset as they are convinced their work is very creative indeed. There is actually some room for manoeuvre on their side (i.e. decisions on how to account for some subjective asset valuations, etc) but still, I think overall, work is pretty straight forward, even if there is risk involved.
Line 2: Thinking in valuation for Mergers and Acquisitions: you need to make assumptions on valuation method, cash flow and discounting parameters but then you are off.
Line 3: Thinking in Internal Audit: you need to understand everything that could go wrong in the area you are looking at, to make sure managers have taken it into account and developed appropriate policies or strategies. The half-way squiggle is because you always end up finding something that you had not anticipated before you get to the end!
Line 4: My current understanding of thinking in design. You end up having to think of a lot of different things, going backwards and then forward again.
Line 5 (not there yet): Thinking in Design - how it really is. I think by the time I finish with the course I should have a more accurate understanding of how design thinking really works and it will be interesting to see how different it is from the current line 4!

Figure 2. E. Figus – changing patterns of creative thinking [11].

5 MODULE ENGINE

One of the challenges in developing a course where there is a deliberate avoidance of convergence has been visualisation of the programme for planning and future growth. In 2007 a research exercise was conducted (by Ashley Hall) to explore the balance of areas covered across the programme during the first year. The exercise [Fig.3] consisted of constructing a set of 'lobes', each of which represented a course module. The lobes were stacked vertically in a three dimensional model to represent the progression of the first year students over one academic year.

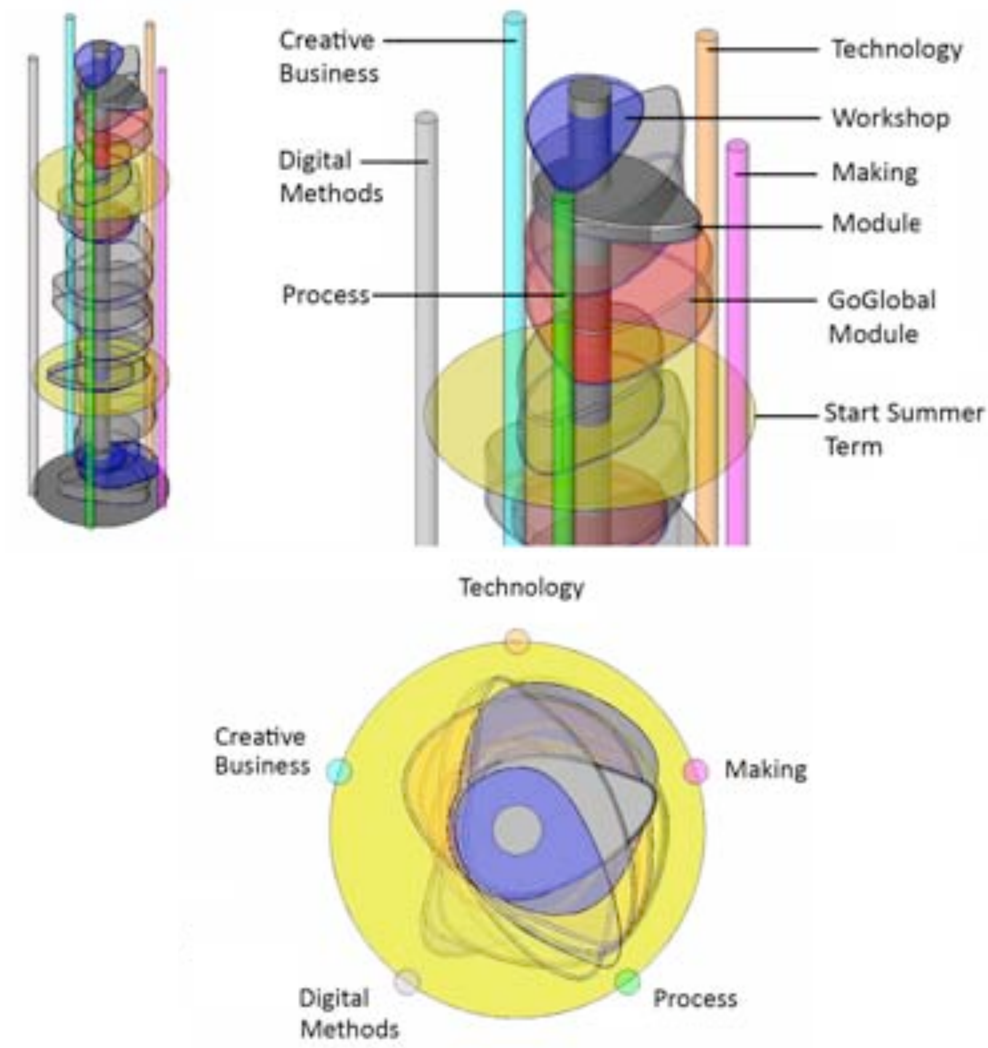


Figure 3. First year programme - Innovation Design Engineering Module Engine.

The five main core-teaching areas of the course guided the forms of the lobes: technology, making and prototyping, design process, digital methods and creative business. Modules that included strong elements of the teaching areas had lobe forms that gravitated toward the relevant pole whilst those with weak areas had lobe forms that moved closer to the central axis. The lobes had a thickness that corresponded to the duration of the module and they intersect where modules overlap. In order to analyse the result the 3d model was revolved into plan view where the densities of the lobe forms can be read in order to give a picture of the spread of teaching areas across the year [plan view at the bottom of Fig.3]. It is also possible through rotation of the model to assess the balance of taught areas from module to module throughout the year.

The engine illustrates a strategy of deliberately contrasting modules in order to create divergent experiences and enhance the space for innovation by non-deterministic overlaps. In essence these are anti-modules whose purpose is to stretch, contrast and question in opposition to the usual format of modules which lead to a convergent narrative. The module programme varies from year to year in number, duration and content to produce a unique experience. The aim of this is to graduate students

with novel skill sets that can occupy the widest parameters of industry. This is driven by the increasing integration of design thinking into business strategy, having a wider impact across many industries and less direct competition amongst graduates. Design thinking is also expending into business and commercial strategy where employers require interdisciplinary skills and flexible problem solving.
The outcome demonstrates strength in the areas of making process, design technology and to a lesser extent digital methods (some of this subject matter is covered in a lecture series and so is not fully represented in the model). Creative business, though it is covered in a lecture series has a notable weakness in the taught programme. As design enterprise is one of the core strengths of the course (as evidenced by graduate careers of which approx 40-50% of graduates each year start their own businesses or become design entrepreneurs) it is clear that this needs to be further strengthened in the course modules. The module engine research exercise was one of the factors that led to the course team in deciding to implement three learning strands. Traditionally the course had a core strength of design for manufacture. In recent years this has been complimented via an experimental design option for students in the final year who showed an interest in exploring more fundamental areas for innovation in areas that would not necessarily lead to a ‘finished product’. In 2008 these two existing options alongside creative business were formalised as three different learning strands: design for manufacture, experimental design and design enterprise. The consequences of operating a non-linear programme is the ‘continuous revolution’ of modules producing complex timetabling and logistics. Students experience some disorientation at the beginning of a programme where there are few consistent weekly activities.

6 CONCLUSIONS

Our design education systems are largely based on criticism and we tend to learn acceptable approaches by avoiding what is deemed wrong by our peers and tutors. We inherently adopt much of this critical attitude and as a consequence filter out creative opportunities through our evaluation of our experiences. A new paradigm should support diverse creative opportunities rather than filtering due to convergent attitudes and teaching styles. Innovation relies on maintaining and enhancing diversity, not by restricting it.
Both the theoretical base supported by Houghton and Robinson [2] in conjunction with empirical course level observation and materials appear to support the idea of the emergence of a paradigm shift for industrial design education from the linear to non-linear models. One may ask what the benefits of this shift might be? In the first instance the aim would be to truly support a more diverse set of creative minds with processes well suited to their natural strengths. Ultimately this has potential to enrich the world of design with greater variety and produce an educational provision that more naturally develops new disciplines and sub-disciplines.
Further research is required to validate the hypothesis of the application of non-linearity at course level by developing the theoretical arguments and by designing models that can fully support the visualisation of non-linear systems in industrial design education. The practical evidence is based on a specific type of course and it requires additional investigation to see how this thinking can apply to other courses at undergraduate level and different intake profiles.

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