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# **IDATER Online Conference:**

## *Graphicacy and Modelling*

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Edited by

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The establishment of the IDATER Online website was supported by Loughborough Design School and the event in December 2010 was held at the University of Limerick. As Conference Editors we believe that the IDATER Online *Graphicacy and Modelling* conference has provided a useful starting position for research in this important area of design and technology education. It has also been an opportunity for the DERG (Design Education Research Group) within Loughborough Design School and the TERG (Technology Education Research Group) at the University of Limerick to collaborate in forwarding this important research agenda. We are indebted to all those who have enabled this initiative concerning the development of an effective strategy for online conferencing to be undertaken.

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*Steve Keirl, Goldsmiths', University of London*

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# Understanding Graphicacy

*Steve Garner*

*Professor of Design, The Open University*

Imagine, if you will, a scene some 30,000 years ago in a fertile valley in what is now southern France. Our ancestor crouches against a wall in a limestone cave – the darkness only locally displaced by a small fire nearby. A hand slowly describes a sinuous and graceful curve on the wall, leaving a trace of ochre from a rock that is being subtly rotated and pressured. Fingers smooth and blend the line as if rubbing life into the rock. The maker stands back. The bison appears to jump and kick in the glittering firelight.

Jump forward those 30,000 years to an architect's office not far from the limestone cave. The architect tentatively strokes a stylus over a tablet and the curved roofline of a future factory emerges on screen, as if built up from multiple candidate thoughts of the maker.

These micro vignettes can be seen as two possible bookends of the human capacity for graphicacy. This is more than the making of representations. Both people synthesised their capacity for envisioning worlds that have been, are, and can be. Our ancestor recreated the spirit of past hunts and in doing so took possession of a powerful talisman for hunts to come. The architect gave tangible form to an intangible idea and this facilitated sharing, testing and developing the work as well as instructing

others in constructing the future. But this is not to suggest that graphicacy is limited to specialist functions in society – shamanic or designerly. Graphicacy defines a fundamental way that humans create and process information that exploits picturing in contrast to the abstract codes of number and letter with which we have become so competent. Graphicacy is the poor relation in comparison to numeracy and literacy which is ironic given the impact visual media have in global culture today. Our visual sense is bombarded with stimuli and we have become lazy. We consume pictures but forget our capacity to make pictures. We have neglected to develop our ability to interrogate pictures, to interpret pictures, to create meaning through pictures.

Clearly graphicacy has much to offer those who seek to engage in design but the real opportunity for research into graphicacy lies in illuminating wider human cognitive capacities and opening up new types of picture thinking for those who have not imagined themselves as picture makers. The field is relatively new and we don't yet have an agenda for inquiry into graphicacy. We need to adopt a multidisciplinary framework and build on the foundations provided by, for example, geographers and human scientists as well as artists and designers. The challenge is to reveal the role of graphicacy in human intelligence.





# Online conferencing: designing and innovation

Eddie Norman & Niall Seery

### ***IDATER Online***

In his Keynote Address to the inaugural *IDATER* Conference<sup>1</sup> in 1988, the late Professor John Eggleston discussed the challenges that the introduction of the National Curriculum in England in 1990 would present. Eggleston was concerned about the preparedness of the Design and Technology (D&T) education profession to face these challenges and particularly about the research foundations.

Perhaps the task that this conference needs to lend itself to most urgently is that of recognising that research and development is an integral part of our educational activities. It is something that we have to take on board as an essential component of the whole process of teaching Design and Technology. The need has never been greater than now as we are set to deliver a major expansion of Design and Technology. If one listens to the politicians you will hear that Design and Technology is expected to provide virtually the whole range of the new

learning opportunities that are seen to be particularly relevant to the kind of society into which we are moving.

...At the moment we are in such an uninformed position that we cannot even be specific about what we hope to deliver and therefore we cannot even devise strategies to respond.

(1989:129-130)

One of the key reasons for starting the *IDATER* conferences was to help support the development of a research base in the area of D&T education at that crucial point in the subject's development. There were, of course, several parallel initiatives, both in England and internationally, as indicated in, for example, Norman *et al* (2009), but the essential matter is that the conferences were established to support practice. The research agendas were focussed on underpinning curriculum development, and there was also an expectation that the research would be carried out 'within practice', as described by Eggleston in ending his 1988 Keynote Address as follows.

What I am trying to suggest, very simply, is that we cannot set up a new kind of activity which requires new people doing different things, but rather that we ourselves as teachers, lecturers, writers and administrators need to add research to the work we are currently engaged in. This is an addition, which is neither theoretical

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<sup>1</sup> The first Design & Technology Educational Research and Curriculum Development conference, *DATER88* was held at Loughborough University in 1988. The conference became 'international' in 1992 (ie *IDATER*) as it became clear that the growth of design and technology in schools' curriculum provision was a truly international phenomenon and delegates from all around the world attended the *IDATER* conferences.

nor remote, but immediate, practical and relevant. If we fail to do so then, ultimately, all the other professional activities we undertake will be increasingly impaired and vulnerable. I hope this Conference will present the opportunity for us to make the move before it is too late and provide us with the support to do it well and effectively. (ibid: 131)

It was expected that research in design and technology education would be undertaken by practitioners, and for practitioners. The research would have immediacy and impact, because it would be directly addressing agendas that have derived from practice. Designerly methods would lie at the heart of action research by practitioners (Archer, 1992; Roberts, 2000). These principles

remain central to the research of the Design Education Research Group (DERG) within Loughborough Design School and they have significant implications for the approaches adopted, which can be summarised as follows.

- Research questions derive from practice
- Researchers are also practitioners
- Research is conducted within practice
- Designerly methods of action research are pursued
- Open access publishing of research outputs is preferred
- Partnerships and collaboration are sought after

The history of *IDATER* illustrates these traditions. It operated very successfully as a

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**What is IDATER?**  
 IDATER is the International Conference on Design and Technology Educational Research and Curriculum Development and was held at Loughborough University each year from 1988-2001. Papers presented at the Conference discussed research and curriculum development related to design-related disciplines, to curriculum subjects, and to their associated educational activities. The papers were published in the annual Conference Book and thereby disseminated to a world-wide audience and, in particular, made available to those studying and researching in this field. In 2001 the decision was made to take IDATER Online.

**IDATER Online**  
 When the decision was taken to stop the traditional IDATER conferences and support the establishment of the UK D&T Association's International Research Conferences to succeed them, it was also decided to take IDATER Online. The IDATER2001 Editorial referred to targeted online conferences and these are now happening. We hope you will want to contribute and join in the discussions.

**IDATER Archive**  
 Over 400 papers were presented at IDATER conferences between 1988 and 2001 and these are all now freely downloadable from the IDATER Archive, which forms part of Loughborough University's Institutional Repository. This resource both supports researchers around the world in accessing what we believe to be the largest collection of specialist literature relating to design and technology education, and also acknowledges the excellent contributions made by many researchers during this period.

Quicklinks:  
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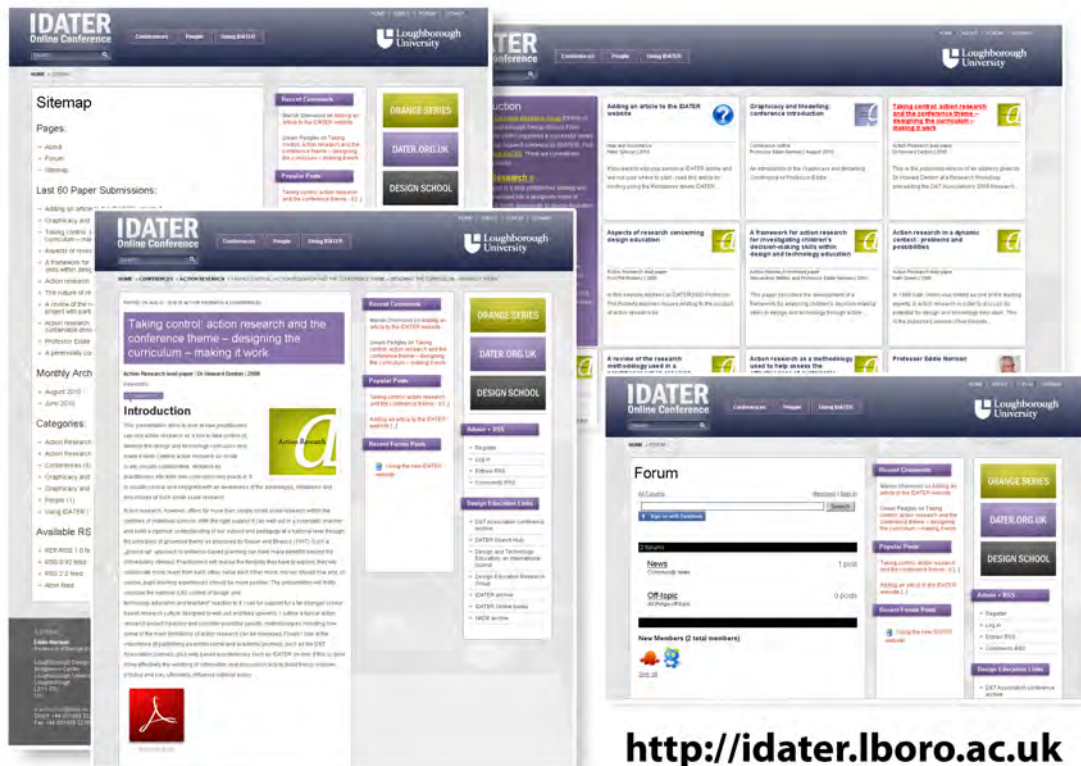
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Figure 1. IDATER Online Mark 1

conventional conference from 1998-2001 and became an annual meeting place for academics interested in design and technology education from around the world. However, by 2001 *IDATER* was losing some of its dissemination routes, certainly within England, as many of the Advisory Teachers from the Local Education Authorities no longer attended. Changes to the management structures within education in England had led to Advisory Teachers tending to take less subject-specific roles, and the conference risked losing its links to practice. The Design and Technology Association was a keen supporter of *IDATER* and took over the running of the conference from 2002 in order to ensure that these links remained strong. Both the *IDATER* archives (1998-2001) and the

*Design and Technology Association's Education and International Research Archives* (2002 onwards) are freely downloadable from the Institutional Repository at Loughborough University. Loughborough University also maintains *Design and Technology Education: an international journal* (an open access international journal), and its predecessors (from 1970 onwards) on its servers. All of these resources can be accessed from [www.dater.org.uk](http://www.dater.org.uk) and searched simultaneously. Open access to research outcomes is essential if all practitioners are to be make use of them in supporting their research.

*IDATER Online* emerged from the discussions held about the future of *IDATER*



<http://idater.lboro.ac.uk>

Figure 2. *IDATER Online* Mark 11

in 2002. Whilst it was clear that the Design and Technology Association could maintain the links between research and practice by running its education and international research conferences in parallel, the experience of running the IDATER conferences had suggested that there was a need for a different kind of contribution. There was a tendency for research contributions not to make all the progress they might, because they were not always founded on the available prior art. Within design education research, the sources of prior art go wider than published literature and extend to practice itself, in the same way that artefacts in design museums embody knowledge about designing. There was a need to establish the 'state-of-the-art' in particular topics and it was with that goal that *IDATER Online* was established.

The first *IDATER Online* conference concerned *E-learning in Science and Design and Technology* used the interface shown in Figure 1 and was completed in 2006. Although it had its successes, for the Conference Director there were a number of issues, most notably unwelcome spam email postings. Consequently the interface was redeveloped as shown in Figure 2 using *Wordpress* in order to resolve this problem. An evaluation is on-going, but whatever its outcome turns out to be, IDATER Online Mark 11 can be seen to lie within the DERG traditions of supporting research within practice, open access to research outputs and seeking partnerships and collaboration. The validation of these research goals in joining with the University of Limerick to establish the second *IDATER Online* Conference on 'Graphicacy and Modelling' are at least as important matters to develop as the technical operation of the website, although they are inevitably related.

### **Graphicacy and designing in Irish education**

The link between design education at post primary level and professional designing is less well defined in Ireland. The Irish education system has a strong tradition in what can be described as a '*craft-orientated approach*' (Carty and Phelan, 2006) to technological education, with a history of focusing on vocational objectives. This heritage adds a layer of social and cultural complexity to the research questions that focus on the role that graphicacy and modelling play in establishing competencies, curriculum, and educational objectives.

Technology education in Ireland has witnessed unprecedented change at Senior Cycle level with the implementation (2007) of two new design driven technological subjects; Design and Communication Graphics and Technology. Their implementation into the national curriculum made apparent the need to question the definition, nature and meaning of designing within the technological subject and as a broader human capacity. It is proposed that the implementation of the 'new' curriculum provides students with the opportunity to develop a skill set that will allow them to explore and learn in a variety of disciplines through the medium of design. The analytical and design driven approach is envisaged to form the core of a subject that encourages students to become enterprising, creative and empowered during their learning experience (NCCA, 2007).

When put in context, developing new treatment of content and specifying learning outcomes that go beyond acquisition and application of knowledge forms an explicit challenge that calls for a tangible response. Coupled with a philosophical shift in objective this presents a dichotomy for the

practicum, where preserving past knowledge and practices must not be a limiting factor of future progression (Benjamin, 1939). At the core of the challenge facing contemporary teaching, learning, and assessment in graphical education is knowing what to value. The emerging global debate highlights the importance of identifying these contemporary values.

Sharing the concerns raised by Professor John Eggleston in 1988, the Technology Education Research Group at the University of Limerick (TERG-UL) was established in 2010 to identify and investigate the research foundation necessary to support educational reform.

The complex views of design education as a vocationally or academically orientated subject or even a broader conception of education must be considered. The philosophical position grounded in a modernist protection of tradition or a postmodernist view that embraces difference and plurality sets the context for the research agenda. Notwithstanding this complexity, there is a need to empirically evidence content, capability and pedagogy.

Understanding the relationship between graphicacy, modelling and designing, helps establish not only what we teach but how we teach. Establishing the core subject content knowledge must inform the research agenda in design and technology

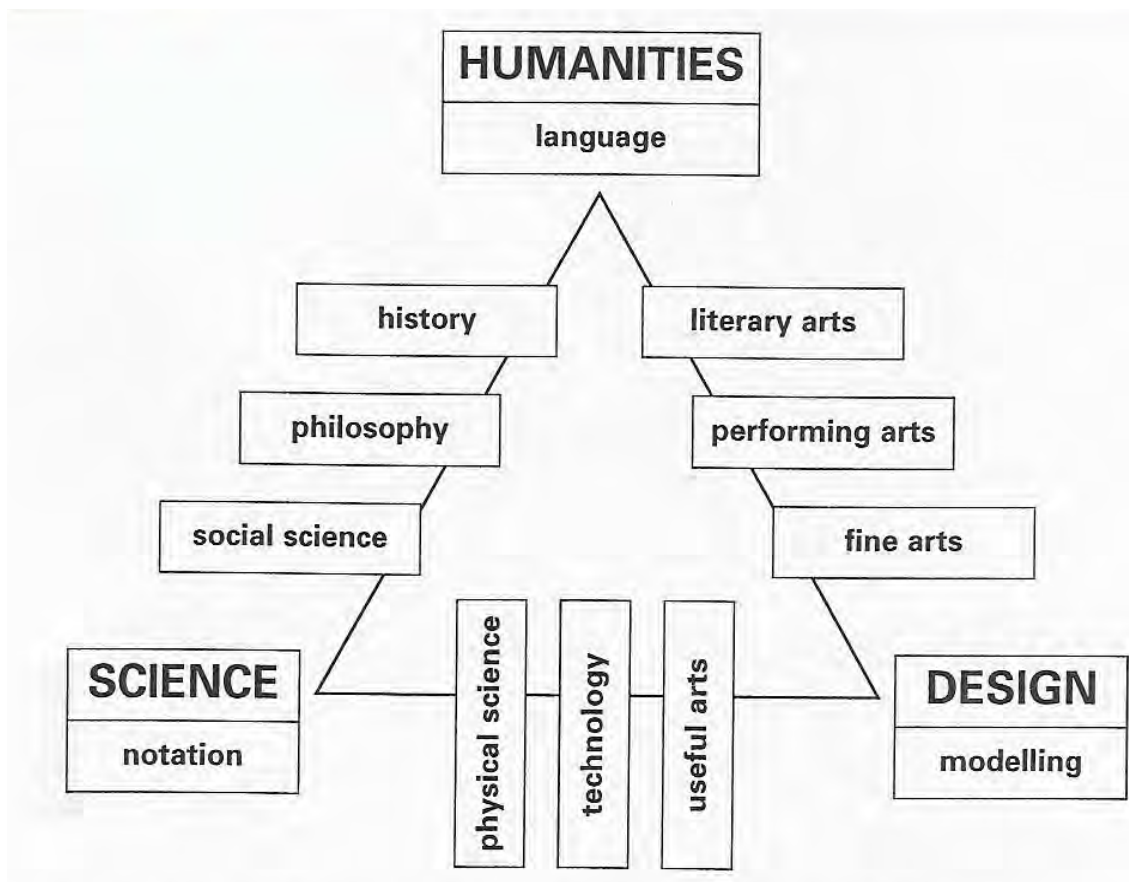


Figure 3. Design as a Third Culture (Archer et al, 2005:12)

**Graphicacy and modelling**

In addition to its current importance in Irish education, the topic of 'Graphicacy and Modelling' emerged from a number of other sources. Modelling has been identified as the language of designing since the work of the Design Education Unit at the Royal College of Art in the 1980s. This was headed by the late Professor Bruce Archer, who made the case for 'Design as a Third Culture', as indicated in Figure 3 (Archer *et al*, 2005). However the relationship of modelling and designing is not straightforward to define. Modelling plays a key role in Science, and also arguably, the Humanities.

Figure 4 begins to illustrate the complexity of the relationship between modelling and designing, which has been the subject of on-going debate within the DERG, and, of course, beyond it. This diagram clarifies the need to focus on the fundamental questions of 'What makes designing possible?' and



Figure 4 The relationship of modelling and designing

'What is the relationship between designing and modelling?'; and in relation to a particular designer, 'What roles do numeracy, articulacy, literacy and graphicacy play? Hence, some of the reasons for the emergence of a research agenda relating to graphicacy become apparent i.e.

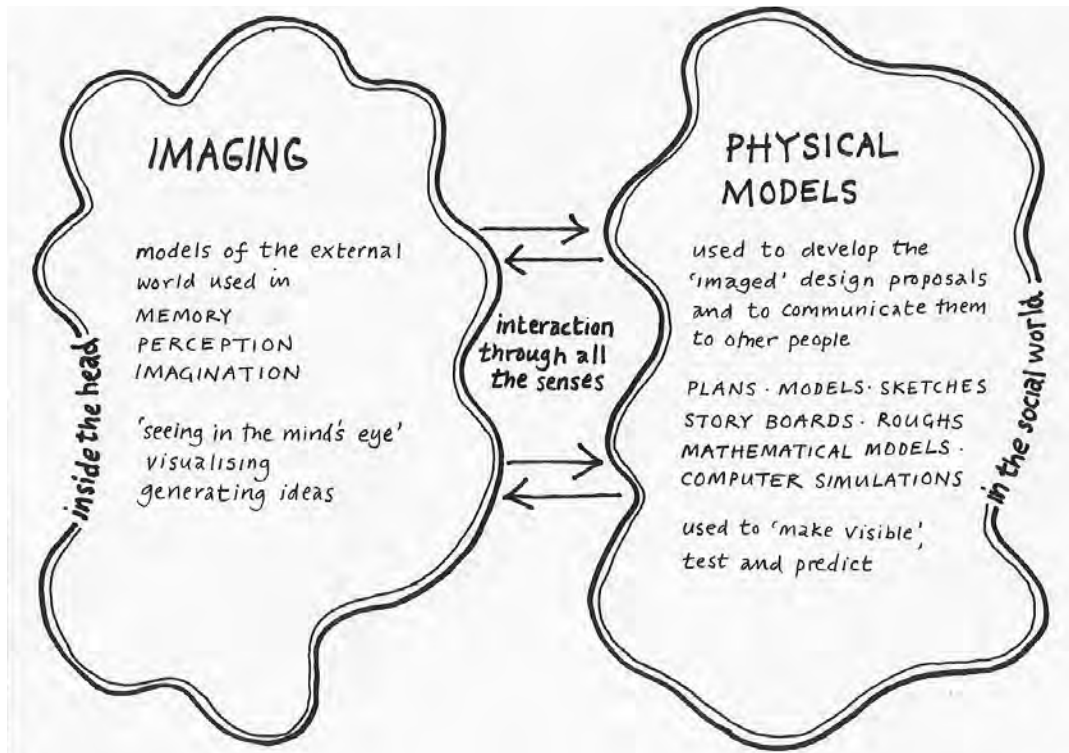


Figure 5. Modelling (Baynes, 2009a: 51)

- If design can be driver for economic growth, how can it be supported?
- If it is intended to move towards a competency-based curriculum, what competences should be central?
- If the requirement is to develop competence in graphicacy, then how can continuity and progression be expressed?
- If visual culture is becoming a more significant aspect of education, how does this relate to the communication of knowledge?

So from national economic and education policy to pedagogy and instructional design, graphicacy and modelling are emerging agendas.

### Modelling and designing

Figure 5 shows the diagram that was used by Ken Baynes and others to describe the relationship between modelling and designing in the 1980s. It remains very effective in demonstrating the relationship of imaging and physical modelling and notes the interaction through all the senses. Archer's description of designing from the same era remains equally pertinent. In an important paper given at the Royal Society of Arts, Archer described how Britain's industrial future was dependent on a wider appreciation of the importance of design. This is what he said.

Design is described as **useful** to distinguish it from the expressive arts, many of which explicitly deny there is operational value to their expressions.

Design is described as **productive** to distinguish it both from Science, which is explanatory, and from Humanities, which are reflective, and to place Design in the world of action. Design is always seen as setting in train the

production, and the introduction into the world, of some real thing, system or change in behaviour.

Design is described as **intentional** to distinguish it from serendipity, or discovery by chance, and to place it in the social and commercial world, where practitioners are obliged to make judgements on difficult and complex issues, and to take decisions in the face of imperfect information and the capricious turns of event that confront everyone in the practical world.

Design is described as **integrative** to reflect the fact that a design has both to be complete and coherent internally, and to be well adapted to the environment in which it will be sold and used. A designer has the right and the duty to employ information drawn from any and every field of knowledge that happens to be relevant to the case in hand. In this sense, the body of knowledge in support of Design has to be regarded formally as unbounded.

Design is described as **inventive** because it necessarily demands the introduction of something new. Whilst it is not completely unknown for a designer to be asked to produce a specification, drawings or data for an absolutely standard, unoriginal product, such a task would not normally merit the description 'design'. The inventiveness of Design is in many ways its most distinctive feature. The word 'creativity' is often used in this context. The term 'creativity', however, more properly describes a combination of inventiveness with productivity. Inventiveness itself has many facets. A design may be inventive in a functional sense, that is, it may perform an operation or supply a service that has



not been offered before. It may be inventive in the operational sense, that is, it may perform its function in a new and more efficient or more convenient way. It may be inventive in the technical sense, that is, it may embody a mechanism or a construction that has not been proposed before. It may be inventive in the sense of offering aesthetic, stylish or marketing configurations that have not been seen before.

Finally, Design is described as **expedient** because design activities are justified by their results, rather than their reasons. In contrast to the overriding importance of methodology

in the conduct of Science, the conduct of Design is validated by its efficacy rather than the rigour of its methods. Designers can, and do, on occasion, seize upon chance information, adopt capricious ideas and exercise untidy methods in the course of a project. None of this matters if it delivers a satisfactory result. The two procedures in design methodology that really do need to be conducted rigorously are the procedures for determining the precise design requirements and the procedures for determining the validity of the design result.

(Baynes, 2009b: 42-43)



Figure 6. Allowing a language of form to develop (Baynes, 2009a:75)

*The question was: what form should the building take? The City Palace Tower clearly needed to be something more than functional. Could the form of the building somehow represent the idea of marriage? The double helix familiar from genetics came to symbolize the idea of union. Drawing proved to be the perfect way to explore this interaction between form and meaning. Sketches could quickly give shape to ideas about natural forms and building structures. The fact that they were quick to do – a kind of shorthand – helped to stimulate creative thinking.*

So, how much more do we really know now, 30 years or so further on? There have been important contributions, such as Hope (2005) who explored the types of drawings that young children produce when designing; Storer (2005) who reflected on the implications of the way professional designers use drawing for teaching undergraduate; and Pulé and McCardle (2010) who have researched the use of different forms of modelling, including 2D and 3D models, as metaphors in the teaching and learning of electronics. And good practice in the use of modelling in designing is also well understood. Consider for example the following two figures from a sequence of drawings that featured in as the 'From Russia with Love' exhibit in the recent Quick on the Draw Exhibition, which was curated by Brochocka-Baynes (2008-2009). The exhibit concerned a tower being designed by Edinburgh architects RMJM for

Moscow city centre. Figure 6 shows how the appropriate use of sketch modelling allowed a language of form to develop. Figure 7 shows a computer generated model of the tower in place. The full sequence of drawings can be found in Baynes (2009) and illustrates the use of detailed technical drawing and architectural models and computer simulations of the interior of the building.

*In Moscow, the City Palace Tower will not only contribute to the architectural dynamic of the city, it will add to its poetic and cultural dimensions.*

*Using CGI – computer generated images – it is possible for architects to give extraordinary reality to their proposals for future buildings and environments.*



Figure 7. The tower in place (Baynes, 2009a:76)

The *IDATER Online* conference on 'Graphicacy and Modelling' was an attempt to establish the position in relation to one aspect of the research agendas underpinning the understanding of designing. The complexity of the research agendas associated with such a developmental model of human capability is immense. This was further illustrated by Doyle's analysis of technicity (2004), which marshalled recent research evidence from studies of human evolution and casts these conceptions about designing from the 1970s in a new light. (This was discussed by

Norman and Pedgley (2005)). Human decision-making is an expression of the art of making judgments based on incomplete information about existing factors and future consequences. This is the essence of design activity, and hence then of the existence of products and systems and their associated technologies. The role that values, heuristics and emotions must play is equally evident. So, without in any sense denying the existence of these complexities, this *IDATER Online Conference Book* is placing a 'line in the sand'.

August 2011

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## Vision, modelling and design

Ken Baynes

### Abstract

*The paper analyses the interaction between homo sapiens' remarkable visual acuity and the emergence of 'designerly thinking', particularly the use of modelling as a way of developing proposals for future designs. The importance of visual/spatial models in design is identified. New modelling media emerge in response to social, technological, environmental and economic factors and have had the effect of enlarging humanity's 'perceptual span'. A table is presented showing the interaction between modelling and graphicacy in design activity and awareness.*

### Introduction

It is widely appreciated that graphic media are important in the practice and understanding of design. This is hardly surprising because an essential aim of design activity is to conceptualise and visualise some aspect of the future – a place, product or communication. However design is not exclusively concerned with the visual world. On the contrary, it has to deal with the total reality of any design proposal.

The aim of this paper is to analyse the interaction between *homo sapiens'* remarkable visual acuity and the wider scope of 'designerly thinking', particularly

the use of modelling as a way of developing proposals for future designs. The intention is to clarify the importance of graphicacy as an element in design education at any level.

### Vision and mind

The eye is an exquisite physiological device. It receives light and by means of the retina can convert it into signals which the brain can interpret. However, the eye does not 'see'. This interpretive work is done by much more complex neuro-biological structures in the brain. An astonishingly large proportion of the brain is devoted to 'seeing', particularly recognising faces, detecting movement and recreating the external world as a vivid, brightly coloured, three-dimensional picture show.

In evolutionary terms it is easy to understand that superior vision would give an advantage to primates moving from the tree tops to become hunter gatherers. Biologists identify stereoscopic colour vision as one of the four key elements which may have led to the evolution of *homo sapiens*, the others being:

- Group living
- Finely controlled and structured hands
- Hunting

Each by itself would not have been decisive, but taken together could have provided a dynamic for developing human intelligence in a particular direction.

What direction? Towards understanding a world of cause and effect. Ultimately, to control and exploit the natural environment and create a made environment within it.

Evolutionary biologists describe *homo sapiens* as occupying the 'cognitive niche' in the natural world. In *How the Mind Works*, Stephen Pinker highlights the special character of our 'big brain' as it operates within and on the surrounding environment. Its unique capability is to be able to construct, manipulate and respond to a cognitive 'causal model' of the world. It is this mental construct, formed by the interaction of our brains with sensory data and experience, which enables us to act in ways which are not found in other animals.

Many species display extraordinary powers and all have to react 'intelligently' to their particular environmental situation. But these are specialised behaviours, closely fitting the species involved to a highly defined evolutionary niche. Humans are unique in displaying more generalised kinds of behaviour. Their strength is in their adaptability. Humans can produce behaviours which are novel and which respond to changing circumstances.

Pinker (1997) writes:

The manipulations [used by people] can be novel because human knowledge is not just couched in concrete instructions like "How to catch a rabbit". Humans always analyse the world using intuitive theories of objects, forces, paths, places, manners, states, substances, hidden biochemical essences, and, for other animals and

people, beliefs and desires. People compose new knowledge and plans by mentally playing out combinational interactions between these laws in the mind's eye.

The mind's eye of *homo sapiens* has evolved in such a way that we can remember and model the past, consciously experience the present and speculate and model possible futures. This past, present and future perspective is a powerful cultural construct used by humans to give meaning to their lives and purpose to their social groupings.

By using their capacity to model alternative futures, humans have linked 'thinking' and action in a dramatic and effective way. Combined with the development of tools, this speculative, forward-looking orientation has given *homo sapiens* effective dominance of the planet. Designing is one of a number of 'intentional activities' in which humans use their causal modelling ability to shape the future.

Since designing is concerned with the future of the made environment and the objects and images within it, it is easy to see that *homo sapiens'* remarkable visual acuity may have had an important role. As already noted good vision and quick, intelligent, cooperative response will have been essential for the success of hunter gatherers. They would also have benefited from a powerful visual memory and by 'seeing in the mind's eye' to plan future expeditions and decide tactics. It turns out, however, that good vision was also instrumental in cognitive and even philosophical developments, providing the 'big brain' with a significant visual world full of stimulus and meaning. Pinker (1977) describes the cognitive importance of binocular, colour vision in this way:

Depth perception defines a three-dimensional space filled with movable solid objects. Colour makes objects pop out from their backgrounds, and gives us sensation that corresponds to the stuff the object is made of, distinct from *our* perception of the stuff.

Within acute vision lie the roots of important abstract concepts, dividing a 'what' system (for objects' location and their shapes and compositions) from a 'where' system (for objects' location and motion).

Even [today's] scientists, when they try to grasp abstract mathematical relationships, plot them in graphs that show them as two – and three dimensional shapes. Our capacity for abstracted thought has co-opted the co-ordinate system and the inventory of objects made available by a well-developed visual system.

Pinker focuses on scientific meaning but, of course, the meanings that can be communicated visually range across the whole of human understanding and, in the form of graphic notation, interact with language and music. Any environmental meaning is likely to contain a visual/spatial element. The emergence of stereoscopic, colour vision and models related to it, is clearly beneficial for 'designerly thinking'. Designers need to see objects 'pop out' vividly from their background and to be able to distinguish between 'stuff' and the 'shape of stuff'. They need to appreciate the distinction between 'what' and 'where'. Equally they need to be fluent in the use of plots, diagrams, formulas and words that represent or model visual/spatial qualities.

When J C Jones (1970) identified the value of engineering drawing as an essential tool of the industrial revolution, he described its unique importance:

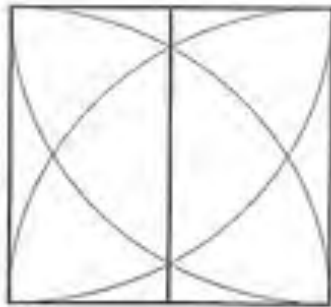
The effect of concentrating the geometric aspects of manufacture in a drawing is to give the designer a much greater 'perceptual span' than the craftsman had. The designer can (by the use of a drawing) see and manipulate the design as a whole and is not prevented, either by partial knowledge or by the high cost of altering the product itself, from making fairly drastic changes in design. Using his ruler and compasses he can rapidly plot the trajectories of moving parts and predict the repercussions that changing the shape of one part will have upon the design as a whole.

The notion of an increasing 'perceptual span' is important in understanding the success of designerly thinking in shaping the human environment. The development of new ways of visualising and defining possible futures was the prerequisite for environmental and technological change. Historically, a graphic element has always played a key role in the emergence of new ways of modelling design ideas.

### **Visual/spatial models**

The functional link between graphicacy and designerly thinking can be found by considering what it is that designers are trying to do. The modelling media used by designers (and non-professionals engaging in design activity) have to be able to make visible and accessible a complex mix of qualities. Designers are attempting to define places, products or communications that could exist in the future. There are certain core aspects of future reality which cannot effectively be modelled in language or number.

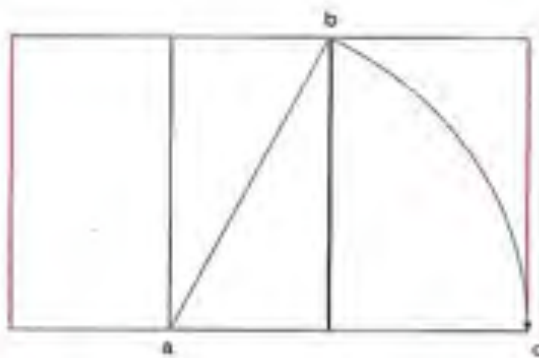




**The Golden Mean**

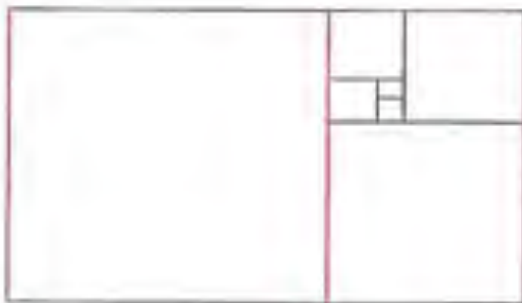
Start with a square and draw an arc from each of the four corners.

Where the arcs cross draw a vertical line cutting the square in half.



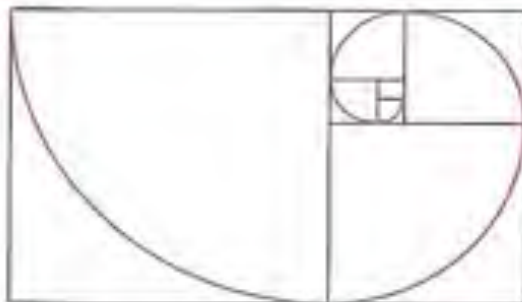
**The Golden Section**

Place the compass at the point (a) where the vertical line meets the base and draw an arc (b-c). Join up the points to construct the Golden Rectangle.



**The Golden Rectangle**

The rectangle can be further divided to repeat the same configuration ad infinitum.



**The Golden Spiral**

Draw arcs from the corners of the squares to create an ever-growing spiral.

Figure 1. Proportion cannot be described in words though words are needed to describe how to construct the figures.

Colour provides an immediately understandable example. It can only be discussed or evaluated by reference to actual examples or models

'Red, what kind of red?'

'This kind of red'

'Oh, I see what you mean'.

Although colours can be translated into notation to describe their wavelengths as a part of a cataloguing system, a particular tone or hue cannot be consciously perceived or evaluated without a visual reference to itself or to other contrasting or slightly different colours.

Proportion is similarly impossible to perceive except by reference to itself. It can be expressed numerically and to some extent described in words, but the example has to be present in actuality, as a model or in the imagination, before it can be appreciated or manipulated. For example, diagrams of the Golden Section (Figure 1) can use language to give instructions on how to construct the figures and their mathematical properties can be expressed in numbers, but to appreciate their impact on our senses and consciousness something more is needed: in this case, a diagram.

Eugene Ferguson makes the same point in relation to engineering design:

Certainly it is very difficult to transmit through the medium of natural language or scientific notation knowledge of certain sorts of dextrous skill or sensory discrimination, or to render into natural language adequate equivalents of, say, musical notation or engineer's orthographic drawings of mechanisms. (Ferguson, 1992)

In the design field what kinds of 'equivalents' are required? Here is a selection of physical properties, aesthetic qualities and spatial relations that are difficult (or impossible) to convey in natural language:

COLOUR  
SPACE  
FORM and SHAPE  
MOVEMENT  
STRUCTURE  
DISTANCE  
PROXIMITY  
TEXTURE  
PATTERN  
SPATIAL RELATIONSHIPS  
SCALE  
PROPORTION  
VISUAL RHYTHM

To these essentially visual/spatial properties we could add those to do with sound/noise and, indeed, any properties of the natural or made world that impact on our senses and so our minds and behaviour. For the designer these properties underlie and translate into the specific forms and constructions found in the made world:

LANDSCAPE  
TOWNSCAPE  
TOWNS  
VILLAGES  
HOUSES  
PUBLIC BUILDINGS  
SHOPS  
PRODUCTS  
TRANSPORT SYSTEMS  
VEHICLES  
CLOTHES  
MACHINES  
TOOLS  
EQUIPMENT  
ENTERTAINMENT MEDIA  
GRAPHIC IMAGES

A further list would move from physical things, places and communications to deal with qualities which people might value in those things, places and communications:

PRIVATE  
CONVENIENT  
BEAUTIFUL  
EXCITING  
TRANQUIL  
IDENTITY  
TRADITIONAL  
FASHIONABLE  
MODERN  
PROGRESSIVE  
COST EFFECTIVE  
PURPOSE-BUILT  
HOME MADE  
METROPOLITAN  
RURAL  
HIGH-SPEED  
RELAXING  
GLOBAL  
LOCAL  
GREEN  
RESPONSIVE  
COMMUNAL  
PROGRESSIVE  
CLEAR  
SIMPLE  
EASY TO USE

These lists only provide a preliminary sketch of essentially non-verbal aspects of design activity and awareness. Notice how each word evokes a visual response. 'Town' has one slide-show in the mind; 'Village' a related but quite different one. 'Exciting' has one visual range, 'tranquil' another. The imagery at play deploys qualities from the first list: 'colour', 'form', 'movement' etc. The intention here is to highlight the interconnectedness of three different visual 'languages' that can be used in designerly thinking:

- VISUAL/SPATIAL QUALITIES
- PHYSICAL PLACES, THINGS and COMMUNICATIONS
- HUMAN VALUES AND MEANINGS

## Perceptual range

Earlier I referred to the ability of a new modelling medium to increase the 'perceptual range' of human beings. There is a powerful visual element in the perceptual range of the human mind. Language, and the way grammar, vocabulary and literary forms are deployed in a particular culture of course shape the thoughts that people can think. But graphic 'language', the visual models deployed in a particular culture are also media for thought and, importantly, the imagination.

In this context, it is hardly surprising that the earliest imagery known concerns animals and sexuality. When a hunter dressed as an animal, the visual/spatial identity of costume and head-dress created spiritual meaning. This is visual power at its most elemental but graphic media also permeated and enabled sophisticated societies, just as they do our own culture. Consider, for example, the perceptual significance of geometric figures or geographically accurate maps. They do not simply present 'facts' in a particular way, they also help to create a new way of viewing the world. Crucially, they provide effective ways of being 'in control' and of planning the future.

It is striking that *homo sapiens* did not emerge complete with a ready-made set of 'causal models' with which to grasp the world. A remarkable aspect of the human mind turns out to be its ability to develop new and more efficient causal models – and (eventually) to discard models that prove unreliable. Historically, new modelling media appear to have emerged in response to the pressure of changing environmental, social, technological and economic influences. But they do not seem simply to have been problem solving strategies. It is clear that the human mind

values models for their own sake, for the meanings they create, as well as for their utility. Any revolution in the repertoire of modelling opens up new possibilities for meaning as well as action. Almost certainly the two are intimately connected in the evolutionary pedigree of *homo sapiens*.

In humanity's short history there have been a series of step changes in the evolution of modelling capacity. The invention of writing and the use of number to predict and control proved essential to the emergence of society and technology. But, as we have seen, language and number by themselves were insufficient for the task of designerly thinking. Designerly thinking required the use of cognitive models to see in the mind's eye to imagine and develop ideas and proposals for the future of material culture. A mental 'image' of all the senses was required but the graphic model proved to be particularly cogent.

I have argued (Baynes, 2009) that the industrial revolution, and hence our own industrialised culture, springs directly from step changes in the range of modelling media which began in the Renaissance. A key element in Renaissance thinking was what might be called 'visual exposition'. The era of the printed book saw not only a huge growth in the use of words and numbers to convey ideas, but also the use of images. These 'explanatory' drawings made visible such key discoveries as anatomy, mechanics, structures, geography and crucially perspective. They eventually provided a flexible and versatile visual language of design that is still in use today.

A further step change is being brought about by the computer. In evolutionary terms, computing is extraordinarily new. Yet it is dramatically relevant to the

cognitive niche and the designerly niche within a niche. Digital modelling has not only exponentially increased the designers' perceptual span, it has the potential to make the means to model alternative futures available throughout society.

The Twentieth Century saw the rapid development of broadcast media. Film, TV and mass publishing all handled ideas about the future. It is claimed, for example, that the British weekly *Picture Post* was partly instrumental in creating the popular vision of 'modern' Britain that ultimately helped a Labour government to power in 1945. Similarly, *Woman* magazine, at the height of its influence in the 1940s and 50s had a circulation of 3.5 million and a readership more than twice that figure. It reflected particular aspirations about domestic life but equally helped to form its readers' views about lifestyle.

These media were what we might call 'normative'. They were also 'formative'. They set out to represent shared values and gave visibility to widely held ideas and ideals about the future. They were centralised in their editorial control and industrial in scale of production.

By contrast digital media are dispersed and accessible. They are capable of representing an extraordinary variety of views and viewpoints. They are multifaceted as opposed to normative. However, they can be powerfully formative, allowing diverse groups to come together to support a campaign or viewpoint. Most significantly they are powerfully egalitarian and subversive, operating in personal dimensions beyond the direct control of state, corporations or institutions. Mass and digital media are both image-based.

Although contemporary culture is rich in imagery, a large portion of it is disposable and repetitive – viewed in passing and instantly forgotten. On the other hand, virtual imagery has the potential to show design ideas and proposals with revolutionary clarity and precision. This both makes it easy to invite participation and easy to persuade. It calls for great honesty on the part of the designer and insight on the part of the general public.

Significantly much designing is now carried out by the direct manipulation of screen-based visualisations. Although the computer is an effective tool for handling images, words and numbers, it may prove to be less reliable in modelling

visual/spatial futures complete with their impacts on the human senses. On the other hand, it may well prove more reliable than the previous repertoire of drawings and explanation.

What is clear is that the traditional interpenetration between designerly thinking and graphic models is going to continue. The proposition is that the two were closely linked in the emergence of human intelligence and will continue to enlarge the perceptual span of all human beings and of designers in particular.

The following table sets out to summarise the intimate relationship between designing and graphicacy.

	<b>MODELLING AND DESIGN</b>	<b>GRAPHICACY AND DESIGN</b>
	The capacity and its application to the 'human-made' environment	Vision and its significance for the 'human-made' environment
1	<p><i>Homo sapiens'</i> BIG BRAIN is capable of constructing, understanding and using CAUSAL models of the world. This allows humans (amongst other things) to:</p> <ul style="list-style-type: none"> <li>o React creatively to unexpected situations</li> <li>o Predict – and so control – the behaviour of the physical world, plants, animals and other humans</li> <li>o Plan ahead and work with others to realise these plans</li> </ul>	<p><i>Homo sapiens'</i> STEREOSCOPIC and COLOUR VISION is capable of depth perception which allows humans to experience a three-dimensional space filled with brilliantly coloured, movable objects. This allows humans (amongst other things) to:</p> <ul style="list-style-type: none"> <li>o React creatively to objects and places and to appreciate their visual/spatial ability</li> <li>o Distinguish 'what' from 'where' and so predict and control the behaviour of the physical world, plants, animals and other humans</li> <li>o Manipulate the visual realm to make stored meanings</li> </ul>
2	<p><i>Homo sapiens'</i> unique cognitive ability to deploy causal models is used in every aspect of life. However, MODELLING (in the mind and externally) is ESSENTIAL to DESIGN ACTIVITY. Since designing is about things which do not exist yet, the only way to articulate them is through models - models which 'stand for' and 'make visible' what could be.</p>	<p><i>Homo sapiens'</i> unique cognitive ability to deploy visual images is used in every aspect of life. However, IMAGING (in the mind and externally) is ESSENTIAL to DESIGN ACTIVITY. Since designing is concerned with visual/spatial futures, which do not exist yet, the only way to model them is through GRAPHIC MODELS – models that 'stand for' and 'make visible' what could be.</p>
3	<p>Designers imagine every aspect of future products, places or images. This is sometimes referred to as IMAGING or 'seeing in the mind's eye'. However, designers need also to be able to use 'the mind's ear' and every other sensory descriptor so that they can imagine (for example) appearance, function, economic viability, marketability, and wider social or psychological impacts. This mental handling of future possibilities is what might be called 'designerly thinking'</p>	<p>Designers imagine every aspect of future products, places or images. However 'seeing in the mind's eye' is particularly potent. In a graphic model, proposals are vividly present. The visual is essential to 'designerly thinking'.</p>
4	<p>Designers make professional use of designerly thinking. However, the ability to imagine alternative futures is shared by all humans. This enables people at large to shape their personal and family environments and to understand or 'read' and react to the designed world.</p>	<p>Designers make professional use of graphic modelling. However, the ability to 'read' and make images is shared by all humans. Graphic models help to 'make visible' alternative futures. This enables people at large to shape their personal and family environments and to understand and react to the designed world.</p>
5	<p>Modelling in the mind (designerly thinking) is extended and shared through the medium of externalized models. These take many forms. Words, numbers and images can be used as well as more specialist media such as plans, maps, technical drawings, simulations, prototypes, storyboards and computer programs. These, and the contents of the designed environment, are the active ingredients of design culture.</p>	<p>Much modelling in the mind (designerly thinking) is extended and shared through graphic models. The fluent use and understanding of visual media and an understanding of the visual/spatial content of the designed environment are amongst the active ingredients of design culture.</p>

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## Purposes of drawings in design sketchbooks

Owain Pedgley

*Design decision-making is rarely carried out solely in the mind of the designer. Instead, designers make use of various kinds of media to externalise their thoughts and give design ideas a physical form. One of the most enduring and ubiquitous types of modelling media is the design sketchbook: the collection of pages onto which designers graphically articulate their emerging design ideas. Sketchbooks embody glimpses of design thinking, design management, information processing and communication of ideas. They provide a rich source of documentary evidence on how a designer tackles a particular brief or problem. Nevertheless, systematic analyses of sketchbooks – and in particular the drawings contained within them – are rare. This article is intended to contribute to understanding of how drawings are strategically used by designers in their work practices, both as a communication tool and as a design tool, thereby illuminating facets of two intellectual attributes that are purported as vital to design activity: graphicacy and technicity. A theoretical background on the relations between modelling, drawing and sketching is argued through evidence from literature. Subsequently, a portfolio of drawings and accompanying diary entries focused on product materials and manufacturing, originating from Loughborough University's 'Cool Acoustics' polymer acoustic guitar project, is subjected to a drawing analysis to reveal the purposes of drawings across a*

*long-term (two year) design project. Five categories of drawings were identified: (i) explanations to colleagues, (ii) mementos of ideas coming from existing products, (iii) restating design ideas and archiving information, (iv) recording ideas and decisions taken at meetings, and (v) generating and developing product designs. The article concludes with comments directed at plausible improvements in design education, relating to (i) the level of emphasis placed on drawing for design and communication, (ii) use of drawing as an external memory system, (iii) encouragement of sketching as a design dialogue, and (iv) drawing using digital tools.*

### Introduction

A commonly held misconception is that drawing is an activity to create beautifully crafted illustrations or precise graphical representations. In other words, artists excel at drawing, but for people without an artistic streak, drawing is something that eludes them. Hence, people's response to being asked to draw something is often to say that they are unable to draw. Of course, they are able to draw – to some extent – but the association of drawing with artistic talent is still pervasive. This is despite drawing being an essential activity for many different trades and professions, including of course design.



Drawing is inherently convenient as a way of depicting design ideas in the early stages of a project, and design details later on. It is portable, immediate, and demands equipment no more advanced than a pencil and paper. As Ottosson (1998:112) states, "...pencil and paper is unbeatably fast when it comes to catching ideas [entertained in the mind]. To have a pen or pencil and a piece of paper constantly at hand is therefore very important for anyone who wants to be efficient". However, drawing is not just about putting pen to paper. It is an intellectual activity that links sensing, feeling, thinking and doing. It is extraordinarily versatile and has a large repertoire of forms and uses. Within industrial design, the importance of drawing skills for visual exploration of problem and solution spaces can be easily overlooked in the current era of photorealistic digital visualisation. Design directors and managers will quickly acknowledge this point: ability to draw is a core skill that is still highly relevant today (Weaver, 2009).

This article explores the purposes of drawings as used by industrial designers in their sketchbooks, by synthesising literature sources with a longitudinal study of the author's own design work previously documented as part of Loughborough University's 'polymer acoustic guitar project' (Pedgley, 1999) and exhibited at the recent *Quick On The Draw* exhibition (Brochocka Baynes, 2008).

### **Drawing as modelling**

Drawing is a medium for design representation and can thus be regarded as one particular approach to *modelling* appropriate for design practice (Roberts et al., 1992). In general terms, modelling is the activity directed at constructing representations and predictions of things or ideas. For industrial designers, these are new products and product-service

combinations. Wormald (1997) identifies two fundamental *roles for modelling* in industrial design: to aid communication and to aid designing. These two roles serve a multitude of purposes in industrial design, some of the most common being listed below (Baskinger, 2008; Römer et al., 2001; Johansson, 2000; Welch & Lim, 1999; Ottosson, 1998; Jordan, 1998; Amy, 1997; Baxter, 1995; Itami, 1995; McMahon & Browne, 1993; Yamada, 1993).

- Vehicles for design discussion, decision-making and approval, and facilitating participatory design.
- Formal statement of arrival at a project milestone.
- Synchronisation and storage of information amongst new product development stakeholders.
- Demonstration, test and evaluation of product utility.
- Demonstration, test and evaluation of product expression.
- Demonstration, test and evaluation of product assembly.

As an extension of these categories, and specifically in relation to drawing, Temple (1994) argues that a design drawing is likely to be made for one of three reasons: to make a quick visual representation of entities or environments exposed to the naked eye; to visually recall the physical nature of objects or environments from memory; or to communicate the physical nature of an entity conceived in the imagination. In other words, designers can draw 'what is', 'what has been' and 'what will / might be'.

As well as *roles*, two basic *domains* of modelling can be said to exist (Sener, 2007): modelling in the mind ('cognitive modelling') and modelling with digital and non-digital media external to the mind ('modelling with media'). For this article, focus is on the latter domain of modelling, since drawing is

an externalised form of modelling, alongside storyboards, mind maps, computer simulations, physical mock-ups and so forth. Such external media are carriers of design ideas and may manifest in a variety of forms including drawings, words, and physical models, with the overarching function of making explicit design ideas that would otherwise remain hidden in one's mind or lost from memory (Warburton, 2001; Kavakli et al., 1998). Ottosson (1998:112) describes this further.

When having a problem to solve, thinking with a pen or pencil in hand and a piece of paper in front means a much higher efficiency than without these tools. Actively thinking about a problem is done in the conscious mind; after which the subconscious mind will work further on the problem if no solution is found. The subconscious mind will work hard to find useful solutions without one's attention. Such solutions will often come in a relaxed situation, for example, when driving a car, when watching the television, when lying in bed, when sitting in a bar, when working on a computer, etc. On all such occasions, a pen or pencil and a piece of paper will help to remember the solutions.

Models in external media therefore have use not only for the originator (designer) but also for other new product development stakeholders (e.g. clients, users, manufacturers). They help in the creative process for everyone involved, moving from something imagined to something that exists in reality. With this point in mind, it is important to appreciate that designers' models (and drawings more specifically) are made with an intended user in mind, which largely dictates the content and style of presentation. For drawings, Garner (1997) distinguishes those that are 'private'

(intended only for personal use by the designer) and those that are 'public' (intended by the designer to explain and communicate information to other people). The key differences concern legibility and clarity, as noted by Baskinger (2008:29): "...the expediency (of pen-and-paper sketching) tends to yield visualizations that communicate best to the author/designer but often fail in communicating to others". If it is for personal use only, externalised modelling can be vague and abstract, with one's mind completing the scene. However, for communication to others, models must usually be clear and unambiguous, unless the designer is also present to 'talk through' the model and provide explanation.

### **Theory of sketching**

When considered in its widest sense, the activity of sketching is an essential enterprise employed in writing, music, science, mathematics, design and in any creative enterprise as part of a conceptualisation process, intensively associated with the 'working up' of embryonic and emerging ideas (Temple, 1994). Figure 1 presents a radial word diagram of terms used in literature to describe either the act of sketching or the qualitative characteristics of sketches. A sketch can capture the 'spirit' of an idea without needing to be dressed-up to look pretty or visually arresting (Stokes, 2009). It can contain missing elements, or elements that have yet to be fully defined (Shillito et al., 2003; Kavakli et al., 1998). In this regard, Baskinger (2008:31) notes that sketches "...should not be cherished, nor should they be easily discarded"; rather, they should be seen as "...negotiable ideas that invite others into the conversation to ask questions".



Figure 1. Attributes of sketching and sketches

Contrary to popular understanding, sketching is not tied to any particular modelling medium or to either 2D or 3D representations. For example, card and foam are two *physical* sketch modelling media. Sketch models can be produced in digital media also, for example a mock-up of a graphical user interface or speedy visuals created in Photoshop®. Explorative models are used extensively within design industries to test design ideas and prototype user experiences (Buxton, 2007; Säde, 1999). Nevertheless, despite overwhelming evidence in support of a wide definition of sketching, it is still heavily associated with the act of drawing.

Sketching presents a contrast to more formal drawings, where deliberation and precise dimensional or geometric constraints are present. Sketched drawings are a *means* rather than an *end*;

they are weighted more, in Wormald's (1997) definition, to aiding *designing* than aiding *communication*; and in Garner's (1997) definition of drawings, centre on 'private' drawings. It is therefore no surprise that the vitality of freehand idea visualisation to designers is consistently raised in research studies (Shillito et al., 2003; Hummels, 2000). Most designers consider sketched drawings as essential to their creative processes and will report frustration if unable to visualise their emerging ideas (Temple, 1994).

#### **Sketching as a dialogue**

There exists a well-established body of evidence that sketching (i) supports the cognitive processes involved in idea generation (Wells-Cole, 1992; Goldschmidt, 1991; Fish & Scrivener, 1990), (ii) facilitates further mental

processing operations (Römer et al., 2001), and (iii) frees the mind to *explore* rather than *store* mental images during design ideation (Tovey et al., 2002). One of the most powerful facets of sketching for designers is therefore as a means to reach new ideas or extend existing ones (Garner, 1992; Römer et al., 2001; Schenk, 1991; Temple, 1994; Tovey et al., 2003). Baynes (2009:5) gives one of the neatest explanations for the essence of sketching, stating that "...the designer requires a medium for a continuing encounter with the evolving work."

One of the essences of sketching is that there exists a dialogue between cognitive modelling and modelling with media (Fallman, 2003); between glimpses of ideas in the mind and glimpses of ideas that are externalised. In other words, a two-way communication is present; from mind to media, and from media to mind. Taken with this structure, sketching is a far more powerful and complex activity than just visualising pre-formed ideas. Although the precise nature of interactions between cognitive and externalised modelling is yet to be well defined or deconstructed (Tovey et al., 2002; Römer et al., 2001; Kavakli et al., 1998), designers are familiar with oscillations between periods of thinking and periods of thinking augmented by recourse to external media. Thus, sketching is typically thought of as a dialectic process travelling between the mind's eye and the location of the externalised ideas, which leads the design to evolve toward a finalised proposal (Liddament, 2000; Temple, 1994). As soon as a design 'idea' is externalised, it becomes part of the information being handled to produce the next idea. The process is thus one of interactive generation and incremental improvements, modifications and additions, described insightfully by Ottosson in the context of drawing.

The pencil also helps the brain to be creative because what the eyes see initiates associations in the mind. The movement of the hand while sketching also gives the mind time to think of the solution to a deeper level than if only mental work is performed. As the pencil is simple and the hand movement occurs as a reflex, all brain time can be devoted to the creative problem solving. Using other tools such as the computer keyboard or mouse, or a knife for cutting a model, means that much of the brain has to be used to coordinate fine muscles to produce things properly. When a keyword, picture or idea has been noted on paper, the next idea can immediately be worked on and noted, and so on. The smaller the pictures and notations are, the faster the hand can respond to the flowing ideas. The more ideas that are sketched on a paper, the more ideas will come, as the visible ideas will force thinking to bounce between the new levels, creating ever-new ideas. The most famous architects make many small sketches on paper to start with and fill each paper completely. (1998:112)

Sketching as a *design* tool can be said to function as a reflective conversation (Schön, 1983) between four actors (Woolley, 1998): the designer with his/her design intent, the skill of the designer in using modelling tool(s), the feedback received from the modelling medium, and the externalised emerging model itself. The conversation is enriched through means such as playing, chancing, directing, assisting, accompanying, verifying, complementing, elaborating, evolving, and interpreting (Hummels, 2000; Säde, 1999). Furthermore, inherent in the reflective conversation of sketching is the possibility of serendipity: of stumbling upon valued design ideas or directions as a

result of embracing exploration (Pillers, 1996).

A researcher's problematic task to capture design intent can be alleviated by studying external manifestations of sketching. Mental processes of designing cannot be observed directly, but modelling with media can be understood as a proximal substitute for such observation, capturing significant moments of designers' activities and aiding an outsider's understanding of the creative process as a whole (Temple, 1994). This standpoint is derived from the argument proposed by Fish & Scrivener (1990) that mental imagery processes are likely to be closely linked to image externalisation processes such that mental imagery and visual or tangible outcomes of designing reflect directly off the other. However, a caveat should be issued. Temple (1994) argues that design sketches do not directly represent images held in the mind but rather, they describe a visual dialogue with glimpses, which gradually combine to define the form of the entity being created or developed.

### **Quick On The Draw' exhibition**

The use of drawings across trades and professions was the subject of the recent Quick On The Draw exhibition curated by Professor Ken Baynes and Krysia Brochocka (Brochocka Baynes, 2008). The exhibition, which travelled the UK, Ireland and Cyprus, debunked the idea that drawing is something limited to artistic endeavour. To reinforce the point, the exhibition included an 'A-Z' of drawings originating from architects through to zoologists (Pedgley and Baynes, 2010). Quick On The Draw was organised around a series of case studies, each showing the value and function of drawing as a means to achieving a particular design result.

### **Cool Acoustics exhibit**

One of the major case studies at Quick On The Draw, and representing industrial design, was the Cool Acoustics thermoplastic acoustic guitar project based at Loughborough Design School. Cool Acoustics started out as a design project within the author's practice-based PhD at Loughborough University (Pedgley, 1999) and in the intervening years has grown to become a larger research project focusing on acoustic guitar innovation and credible material alternatives to wood. General aims of the PhD (1995-1999) were as follows.

- To investigate ways in which industrial designers are involved in, and have responsibility for, the subject of product materials and manufacturing.
- To determine if a unique 'industrial design perspective' on materials exists and can be characterised.

The PhD was driven by the following research questions (RQs).

#### **1. Pragmatic aspects (practical factors affecting design decisions)**

**RQ1A.** Do project stakeholders (e.g. clients, manufacturers, users) have influence over industrial designers' selection of materials and manufacturing processes for a product? How are the influences managed and responded to?

**RQ1B.** How does creativity in the area manifest?

**2. Epistemological aspects  
(intellectual attributes affecting  
performance and learning)**

**RQ2A.** What kinds of information, knowledge, values, and skills do industrial designers use when deciding on product materials and manufacturing? How do designers augment their expertise?

**RQ2B.** What activities (cognitive, externalised) do industrial designers undertake to help reach materials and manufacturing decisions? Which deliverables are generated?

Within the PhD, a design project was needed to gather documentary evidence of how materials and manufacturing decisions are integrated into product design decision-making and thus help in answering the research questions. The project needed to be longitudinal, in order to track design activity in detail as it happened across many months of work. Furthermore, the project would be integrated into the PhD in such a way that the author would also undertake the designing. This constituted a form of research enquiry termed by Bruce Archer in the late 1970s as *research through art, design or technological action* (Archer, 2004; Archer, 1999) and more recently referred to as *practice-based research, practice-led research* or *investigative designing* (Pedgley and Wormald, 2007; Durling and Niedderer, 2007; Rust, 2004).

The chosen project was the design of an acoustic guitar made from plastics as an alternative to wood. The detailed reasons behind the selection of this particular project may be found elsewhere (Pedgley et al., 2009). However, briefly, the motivation was to create an affordable and

desirable beginners' acoustic guitar of consistently high quality. The vision was to use polymer (plastics) in place of wood, and the project was thus viewed as a source of 'good data' for an examination of materials and design, since that there was pursuit of innovation from the outset, not routine design or redesign. Not only were certain polymers found to have very good sound quality at low cost, they also opened up radical approaches to instrument design, construction and finishing. From the early PhD instruments, the Cool Acoustics team succeeded in developing and patenting non-wood acoustic guitars that sounded and played just like wood. Some subsequent prototypes were developed with a view to commercial release, for example in collaboration with guitarist Gordon Giltrap and luthier Rob Armstrong (Figure 2).



Figure 2. Secret Valentine acoustic guitar: a collaboration between Cool Acoustics, guitarist Gordon Giltrap and luthier Rob Armstrong

One of the crucial issues in conducting a longitudinal design project under a wider umbrella of academic research is to decide how the design activity can be effectively documented. A 'diary of designing' was chosen as the most effective and efficient method (Pedgley, 2007). Several formats of diary were trialled (Figure 3) before arriving at a preferred set of preformatted stationery for completion at the day's end (Figure 4).

On completion, the diary of designing had systematically captured attention to materials and manufacturing in over **300 detailed diary entries** across **227 project days**, spanning over **2 years**. This was a considerable effort of commitment, discipline and time. In the intervening years, the guitar development folio and accompanying diary of designing became appreciated as a valuable and rare archive of design decision-making. Hence an invitation was received for excerpts of the archive to feature in the Quick on the Draw exhibition (Figure 5).



Figure 3. Trial involving different formats of design diary as a tool for explaining thinking embedded in design sketches

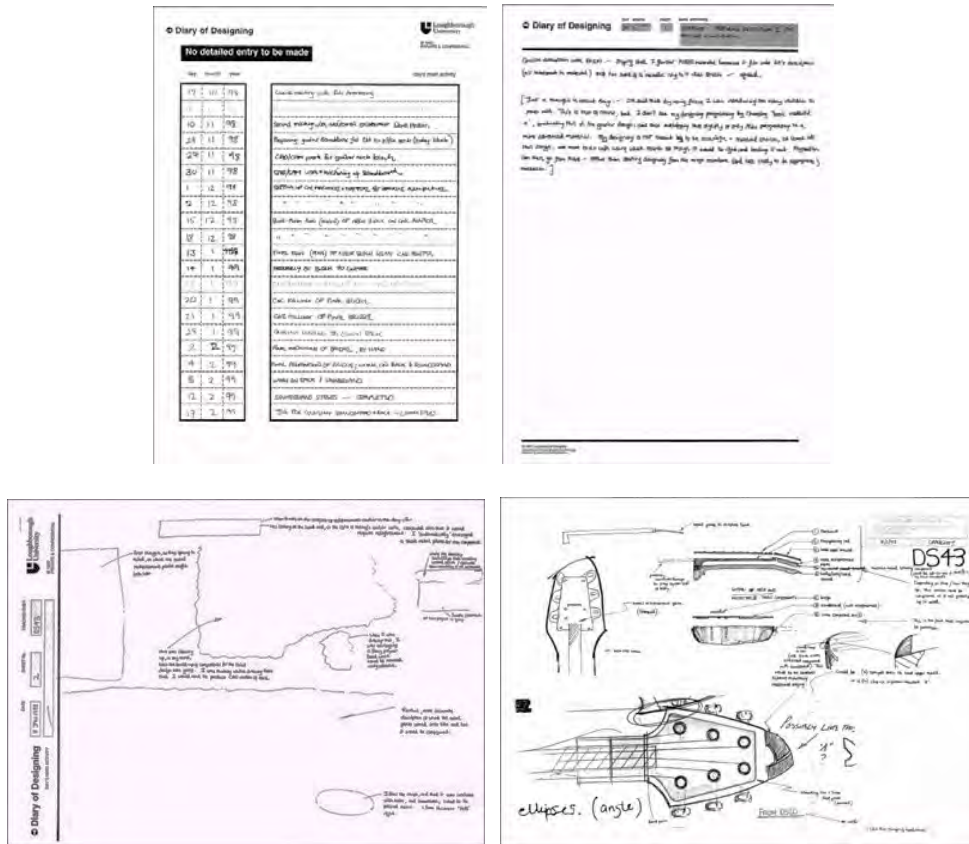


Figure 4. Three types of preformatted sheet used for the diary of designing: summary sheet and detailed entry sheet (top), traced entry sheet (bottom)



Figure 5. Sketches, diary entries and guitars exhibited at Quick On The Draw



### Purposes of drawings

A complete re-analysis and interpretation of the diary of designing data was necessary to examine the specific role of drawing within the guitar project, since this

had been only a peripheral concern during the PhD write-up. One round of re-analysis had been undertaken previously (Norman & Pedgley, 2005), concerning the uncovering of documentary evidence of 'technicity' in action (Doyle, 2004).

Grouping	Technicity characteristic	Rationale / example in Doyle (2004)
Language	1. An organ of social cohesion	Creativity is not <i>in</i> language; instead, creativity <i>co-opts</i> language. (p70)
	2. Intentionality	Related to the human theory of mind. (p68)
	3. Shared memories	Essential for verbal and visual descriptions to be ascribed meaning. (p68)
Deconstructing & Reconstructing	4. Identifying different making strategies	Described with reference to making a ring with different materials and processes. (p69)
	5. Rehearsing alternative scenarios	Linked to imagination and the human theory of mind. (p69)
	6. A secure cultural foundation	Historical evidence is cited suggesting that this is a requirement for innovation. (p69)
	7. Blindingly obvious	Mentioned as a characteristic of 'creative leaps' when retrospectively analysed. (p69)
Drawing	8. Use as an external memory system	Part of the construction process exercised by humans. (p69)
	9. Development to serve a novel application	A technology spiral mentioned in relation to verbal language, but presumably extending also to visual language. (p70)
	10. Use of drawing instruments	Indicated as manual drawing tools, but can conceptually extend to digital design tools. (p70)

Table 1. Ten characteristics of technicity identified from Doyle (2004) by Norman and Pedgley (2005)

Technicity is argued as "...the capacity of behaviourally modern humans to deconstruct and reorder objects, and deploy an external memory system" (*ibid.*, p69). It was the plausible link between technicity and the design and development of new products that motivated the initial reanalysis, largely because technicity exposes uses of verbal and visual languages (drawing) that help illuminate the fundamental nature both of graphicacy (ability to create and decode graphical representations) and modelling more generally.

Norman & Pedgley (2005) used the polymer acoustic guitar project to test the technicity hypothesis that "innovation is to be expected [and that] technicity is its intellectual driver" (Doyle, 2004:70). The study identified ten characteristics of technicity from Doyle's work (Table 1), some specifically referring to purposes of drawings. All ten characteristics were found to be present in the polymer acoustic guitar diary, scattered across varied entries.

Where this present study differs from the 2005 study is in the specific focus and depth of analysis: only diary entries that made reference to sketchbook or log book content were of interest. Nevertheless, some of the entries referred to in the 2005 study are also referred to here. An important facet of the classification used for this present study was its personal nature: the author systematically reflected on the purposes of his drawings, thereby augmenting the purposes of drawings already revealed through the technicity analyses. Five categories were used for the drawings, as follows:

1. **Explanations to colleagues.** Nearly all of these drawings were prepared in advance of meetings so as to illustrate key points to other people.
2. **Mementos of ideas coming from existing products.** These served as sketched and written reminders of the features of existing products.
3. **Restating design ideas and archiving information.** Drawings within this category assisted project co-ordination, especially after extended breaks away. They restated established design ideas, recorded out-of-hours designing, clarified emerging design criteria, and served as a space for recording the findings of information searches.
4. **Recording ideas and decisions taken at meetings.** The drawings here were made to prevent loss of information from meetings, act as a formal record and to refer back to as a resource at a later date.
5. **Generating and developing product designs.** The main use of drawing was as a medium through which product designs were conceived and took shape, and by which ideas entertained in the mind became externally represented. Often dialogues would take place, where the act of drawing or the drawn marks on paper acted as stimuli for further design ideas, setting up a kind of cyclic advantage for designing.

### Drawing portfolio

Diary entries making direct reference to drawings are the focus for this portfolio. It contains 22 exemplars from the many drawings made by the author in sketch sheets and log books during his PhD and thus relate to designs for the very first generation of instruments, and the initial phases of guitar innovation. Tables 2 to 8 present the drawings organised into the five categories and with additional contextual information, as below.

It should be appreciated that all of the diary entries relate only to design activity involving consideration of product materials and manufacture. Other considerations, for example product styling, ergonomics, user research and so on, were not reported in the diary for the reason of being outside the scope of the PhD and specialist area. Such delimitation of content made the task of diary writing plausible and manageable.

Exhibit Number: 1-22

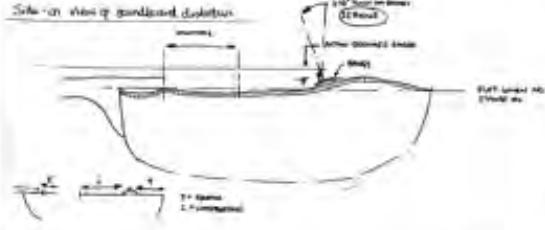
Type:	Sketch or Non-Sketch
Purpose:	One of five categories
Project Date:	Date on which the diary entry was made
Project Day:	<i>N</i> th day (of 227) working on the project
Diary Entry Number:	<i>N</i> th detailed diary entry (of 312)
Drawing Source:	From where the drawing originated, e.g. DS50 (design sheet 50) or LB1:15 (log book 1, page 15)

	<b>EXHIBIT NUMBER</b>	<b>TYPE</b>
	4	Non-Sketch
	<b>PURPOSE</b>	
	Mementos of ideas coming from existing products	
	<b>PROJECT DATE</b>	<b>PROJECT DAY</b>
22.05.96	5/227	
<b>DRAWING SOURCE</b>	<b>DIARY ENTRY NUMBER</b>	
DS03	7/312	
<b>DIARY ENTRY</b>		
<p>"Lining as structural interface was 'assumed' from diagram - then I realised exactly what it was..."</p>		

	<b>EXHIBIT NUMBER</b>	<b>TYPE</b>
	5	Sketch
	<b>PURPOSE</b>	
	Mementos of ideas coming from existing products	
	<b>PROJECT DATE</b>	<b>PROJECT DAY</b>
22.05.96	5/227	
<b>DRAWING SOURCE</b>	<b>DIARY ENTRY NUMBER</b>	
DS03	11/312	
<b>DIARY ENTRY</b>		
<p>"Some of the 'checklist' of tech. features on DS3 have been sparked off mentally from previous encounters with 'guitar design' work, others pertain to more 'general' considerations which are appropriate to any product I may be designing."</p>		

	<b>EXHIBIT NUMBER</b>	<b>TYPE</b>
	6	Sketch
	<b>PURPOSE</b>	
	Mementos of ideas coming from existing products	
	<b>PROJECT DATE</b>	<b>PROJECT DAY</b>
03.07.97	35/227	
<b>DRAWING SOURCE</b>	<b>DIARY ENTRY NUMBER</b>	
DS27	84/312	
<b>DIARY ENTRY</b>		
<p>"This was drawn from a cross-section piece of the removed Ovation [commercial guitar] soundboard - purpose was to draw to my attention the constructional details of this area, as I might want to duplicate the details when I make my prototypes. (I checked my early design sheets DS3 to remind myself of the reasons for this design)."</p>		

Table 3. Drawings for Mementos of ideas coming from existing products

	EXHIBIT NUMBER	TYPE
	7	Sketch
	PURPOSE	
	Restating design ideas and archiving information	
	PROJECT DATE	PROJECT DAY

19.08.97	53/227
DRAWING SOURCE	DIARY ENTRY NUMBER
LB1:34	108/312

**DIARY ENTRY**

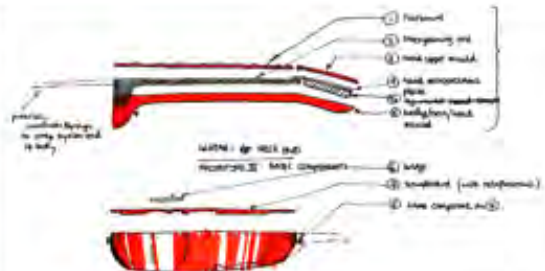
"Learnt that the Forex EPC [special polymer sheet] (or the configuration - lack of stiffening members - that it is currently in) is subject to stretching or a kind of polymeric creep, because the guitar went out of tune overnight."

<p>PC Softening temperature = 152°C (and FOREX)                  PC Melting temperature = 250°C - 280°C                  PC Tensile strength = 60 MPa/m<sup>2</sup> = 600 N/m<sup>2</sup> = 600 kg/m<sup>2</sup> (Each of the two plates)                  PC Young modulus = 2.5 GN/m<sup>2</sup> = 2500000 N/m<sup>2</sup> = 2500000 kg/m<sup>2</sup> (Each 1000 mm<sup>2</sup>)                  PC Coeff. thermal expansion = 0.5 x 10<sup>-4</sup> / °C Density 1180-1220 kg/m<sup>3</sup> (Forex 650 kg/m<sup>3</sup>)</p>	EXHIBIT NUMBER	TYPE
	8	Sketch
	PURPOSE	
	Restating design ideas and archiving information	
	PROJECT DATE	PROJECT DAY

26.11.97	79/227
DRAWING SOURCE	DIARY ENTRY NUMBER
LB1:40	159/312

**DIARY ENTRY**

"The key properties of polycarbonate (both in Lexan and Forex [polymer sheets]) were noted on LB1:40 so that I can make quick reference to them when discussing processing requirements with manufacturers. This is information which needs to be portable, since I do not want to rely on remembering it. Most of the physical properties were taken from the text 'Mechanics of Engineering Materials' by Benham and Crawford."

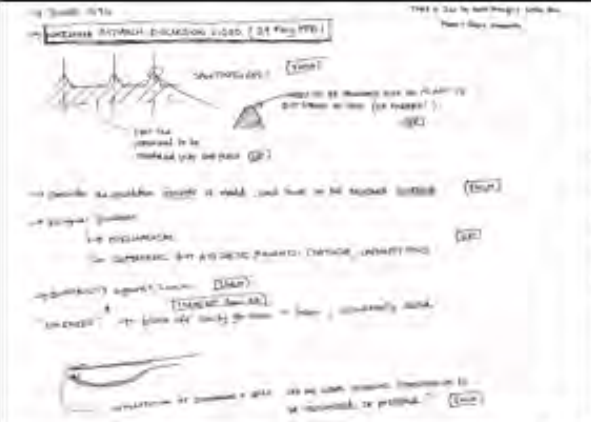
	EXHIBIT NUMBER	TYPE
	9	Non-Sketch
	PURPOSE	
	Restating design ideas and archiving information	
	PROJECT DATE	PROJECT DAY

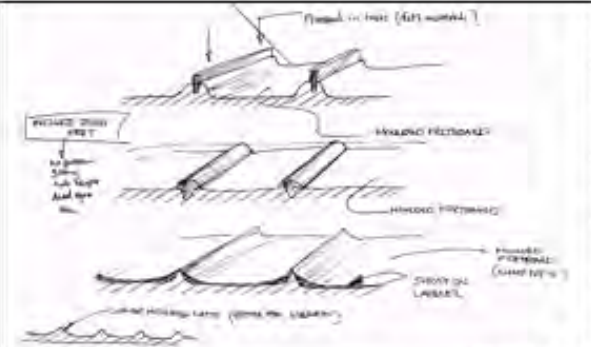
07.01.98	95/227
DRAWING SOURCE	DIARY ENTRY NUMBER
DS43	195/312

**DIARY ENTRY**

"This was clearing up, in my mind, how the build-up of components for the final design was going. I was thinking whilst drawing these that I would need to produce CAD [computer aided design] models of each."

Table 4. Drawings for restating design ideas and archiving information

	<b>EXHIBIT NUMBER</b>	10
	<b>TYPE</b>	Sketch
	<b>PURPOSE</b>	
	Recording ideas and decisions taken at meetings	
	<b>PROJECT DATE</b>	<b>PROJECT DAY</b>
19.06.96	9/227	
<b>DRAWING SOURCE</b>	<b>DIARY ENTRY NUMBER</b>	
LB1:05	25/312	
<b>DIARY ENTRY</b>		
<p>"Technological information has been noted down from the video session 29 May 1996 (...) in the log book. This was to make sure as much information is stored in a readily-used format..."</p>		

	<b>EXHIBIT NUMBER</b>	11
	<b>TYPE</b>	Sketch
	<b>PURPOSE</b>	
	Recording ideas and decisions taken at meetings	
	<b>PROJECT DATE</b>	<b>PROJECT DAY</b>
19.07.96	13/227	
<b>DRAWING SOURCE</b>	<b>DIARY ENTRY NUMBER</b>	
LB1:08	37/312	
<b>DIARY ENTRY</b>		
<p>"Moulded fretboard designs all Rob Armstrong ideas - suggested when going onto the subject of plastic fretboard design."</p>		

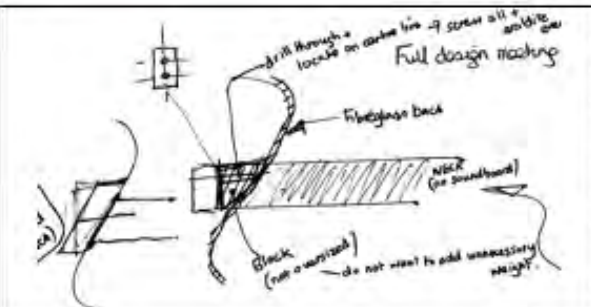
	<b>EXHIBIT NUMBER</b>	12
	<b>TYPE</b>	Sketch
	<b>PURPOSE</b>	
	Recording ideas and decisions taken at meetings	
	<b>PROJECT DATE</b>	<b>PROJECT DAY</b>
21.01.98	103/227	
<b>DRAWING SOURCE</b>	<b>DIARY ENTRY NUMBER</b>	
LB1:49	212/312	
<b>DIARY ENTRY</b>		
<p>"Design sketches of prototype 3 manufacture, for me to visualise what Rob Armstrong was explaining to me. I'll find it easier to make use of this information in the near future when it's in illustration rather than memory."</p>		

Table 5. Drawings for recording ideas and decisions taken at meetings

	<b>EXHIBIT NUMBER</b>	13
	<b>TYPE</b>	Sketch
	<b>PURPOSE</b>	
	Generating and developing product designs	
	<b>PROJECT DATE</b>	22.05.96
	<b>PROJECT DAY</b>	5/227
<b>DRAWING SOURCE</b>	DS04	
<b>DIARY ENTRY NUMBER</b>	12/312	

**DIARY ENTRY**

"Flexing of this section: prior experience tells me about loose protruding sections of material."

	<b>EXHIBIT NUMBER</b>	14
	<b>TYPE</b>	Sketch
	<b>PURPOSE</b>	
	Generating and developing product designs	
	<b>PROJECT DATE</b>	17.10.96
	<b>PROJECT DAY</b>	19/227
<b>DRAWING SOURCE</b>	DS23	
<b>DIARY ENTRY NUMBER</b>	55/312	

**DIARY ENTRY**

"Strengthening ribs on 3D view (experience). Fixing points for moulds (knowledge)."

	<b>EXHIBIT NUMBER</b>	15
	<b>TYPE</b>	Sketch
	<b>PURPOSE</b>	
	Generating and developing product designs	
	<b>PROJECT DATE</b>	03.07.97
	<b>PROJECT DAY</b>	35/227
<b>DRAWING SOURCE</b>	DS27	
<b>DIARY ENTRY NUMBER</b>	85/312	

**DIARY ENTRY**

"Was thinking how to produce the thickness tapering effect using a conventional forming method. Thermoforming came to mind because I 'pictured' drinks cups with different wall thickness."

Table 6. Drawings for generating and developing product designs (1 of 3)

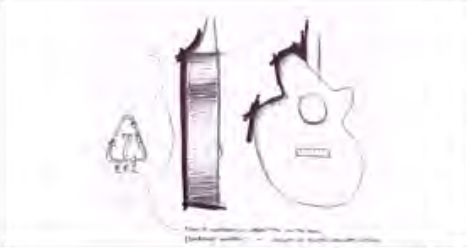
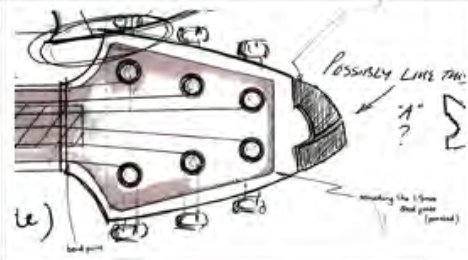
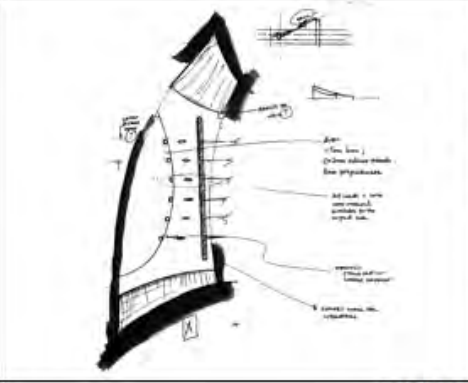
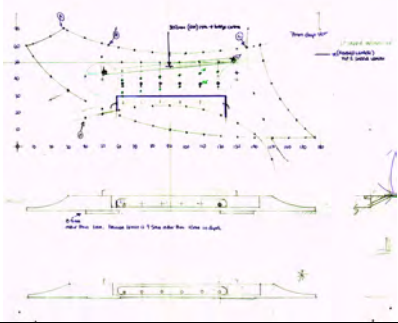
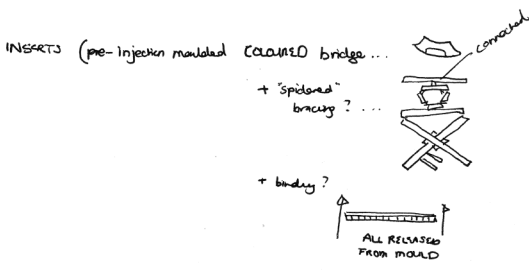
	<b>EXHIBIT NUMBER</b>	<b>TYPE</b>
	16	Sketch
	<b>PURPOSE</b>	
	Generating and developing product designs	
	<b>PROJECT DATE</b>	<b>PROJECT DAY</b>
08.10.97	67/227	
<b>DRAWING SOURCE</b>	<b>DIARY ENTRY NUMBER</b>	
DS30	120/312	
<b>DIARY ENTRY</b>		
<p>"The stimulus for producing a large recycling logo on the plastic body was sparked off by me re-reading my PDS [product design specification] section to do with recycling. Paul Wormald, had given me an information sheet on the standard logos and these two issues seemed to 'click' in my mind. I immediately thought of making the logo as part of a moulding or pressing- and wanted it big to really shout out 'recyclable product design!' - the most suitable surface area without spoiling the form of the product was on the back."</p>		
	<b>EXHIBIT NUMBER</b>	<b>TYPE</b>
	17	Sketch
	<b>PURPOSE</b>	
	Generating and developing product designs	
	<b>PROJECT DATE</b>	<b>PROJECT DAY</b>
07.01.98	95/227	
<b>DRAWING SOURCE</b>	<b>DIARY ENTRY NUMBER</b>	
DS43	197/312	
<b>DIARY ENTRY</b>		
<p>"I saw the shape, and that it was intricate with holes, and immediately linked it to pressed metal. 1.5mm thickness 'felt' right."</p>		
	<b>EXHIBIT NUMBER</b>	<b>TYPE</b>
	18	Sketch
	<b>PURPOSE</b>	
	Generating and developing product designs	
	<b>PROJECT DATE</b>	<b>PROJECT DAY</b>
22.01.98	104/227	
<b>DRAWING SOURCE</b>	<b>DIARY ENTRY NUMBER</b>	
DS45	214/312	
<b>DIARY ENTRY</b>		
<p>"All the while whilst on DS45 I knew that I would be working with 8mm depth polycarbonate and that the bridge would be machined using CNC [computer numerically controlled] methods because of the intricate/precise curves required. When working on the right-most drawing (marked 'X') I had in my mind an image of a block being machined to produce the shape I wanted - using the Department's Workshop 1 machines. I found myself 'extending profile lines' as if they were paths for the milling cutters to follow. I also imagined the milling machine producing the overall edge shape, 1mm or so a time. I concluded that the whole component could be produced on the CNC machines, save a few operations which cannot be performed in 2.5-D machining."</p>		

Table 7. Drawings for generating and developing product designs (2 Of 3)



	<b>EXHIBIT NUMBER</b>	<b>TYPE</b>
	19	Non-Sketch
	<b>PURPOSE</b>	
	Generating and developing product designs	
	<b>PROJECT DATE</b>	<b>PROJECT DAY</b>
	13.02.98	114/227
<b>DRAWING SOURCE</b>	<b>DIARY ENTRY NUMBER</b>	
DS52	245/312	
<b>DIARY ENTRY</b>		
<p>"The bridge has been detailed up, including precise points for the bridge-to-soundboard location lugs and, with the aid of the section drawing showing where the string holes need to go (DS52 bottom right), I was able to determine the distance back from the saddle where the strings should terminate. The drawing showed me that there was enough material to play with (going on the performance of prototype 2 which is still in tact and playing very nicely). The profile of the bridge was plotted out so that it could be described in a CAD [computer aided design] program (next week)."</p>		

	<b>EXHIBIT NUMBER</b>	<b>TYPE</b>
	20	Sketch
	<b>PURPOSE</b>	
	Generating and developing product designs	
	<b>PROJECT DATE</b>	<b>PROJECT DAY</b>
	18.03.98	130/227
<b>DRAWING SOURCE</b>	<b>DIARY ENTRY NUMBER</b>	
LB1:58	267/312	
<b>DIARY ENTRY</b>		
<p>"Had a look at Bralla, DFMA [design for manufacture and assembly] book with reference to injection moulded structural foam. I hadn't realised that it was used so extensively. Picked up the fact that the process creates a smooth skin (in contact with mould) with a foamed core. Made notes on LB1:58 for future use in my section on mass manufacture in my final design report. Had visions in my mind about how the inserts might work - and that holding a 'spider' (see diagram) bracing pattern (one component, pre-injection moulded) would be a lot simpler than clamping each bracing member separately... (I was thinking how to make the manufacturing process simple). The binding I thought could be quite quickly and easily be fabricated by machine with a band saw and appropriate jig (easily automated too)."</p>		

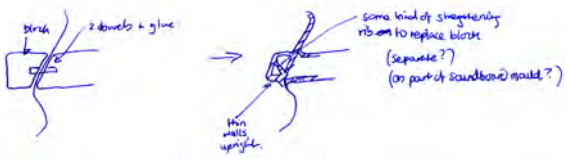

	<b>EXHIBIT NUMBER</b>	<b>TYPE</b>
	21	Sketch
	<b>PURPOSE</b>	
	Generating and developing product designs	
	<b>PROJECT DATE</b>	<b>PROJECT DAY</b>
	27.04.98	143/227
	<b>DRAWING SOURCE</b>	<b>DIARY ENTRY NUMBER</b>
DS55A	284/312	
<b>DIARY ENTRY</b>		
<p>"I used this left-hand drawing to remind me of how the prototype will be constructed around the neck. It led me on to thinking about the same in the mass-manufactured proposal... the block was providing stability, and rigidity in particular - how could this be achieved in the mass manufactured version, using lay-up/moulding? A web of walls I thought, rather like strengthening ribs in injection moulded components... The idea was then superseded on DS55 main."</p>		
	<b>EXHIBIT NUMBER</b>	<b>TYPE</b>
	22	Non-Sketch
	<b>PURPOSE</b>	
	Generating and developing product designs	
	<b>PROJECT DATE</b>	<b>PROJECT DAY</b>
	15.07.98	173/227
	<b>DRAWING SOURCE</b>	<b>DIARY ENTRY NUMBER</b>
DS51	306/312	
<b>DIARY ENTRY</b>		
<p>"When I placed the shell against my table (reasonably dark wood) it confirmed in my mind (and what I'd drawn on DS51) that I'd like the neck and head to be manufactured from very light coloured wood. It looked too dingy and furniture-like with the darker wood."</p>		

Table 8. Drawings for generating and developing product designs (3 of 3)

## Discussion and conclusions

The evidence presented in this article has shown how a designer makes drawings to assist understanding, thinking, working out problems, recording, and communicating ideas and information. The portfolio of drawings from the polymer acoustic guitar project revealed a mix of private drawings (intended only for personal use) and public drawings (intended for communication to other people), corroborating Garner's (1997) observation of such divisions. Five categories of drawing were identified, based on the facility that the drawings brought the designer.

- Explanations to colleagues
- Mementos of ideas coming from existing products
- Restating design ideas and archiving information
- Recording ideas and decisions taken at meetings
- Generating and developing product designs

The vast majority of the drawings in the portfolio were considered to be sketches rather than formal drawings, which underlines that the portfolio mostly contained private drawings for use only by the designer. This was especially the case for the category 'generating and developing product designs': the associated diary entries revealed that the sketching did indeed progress as a dialogue between the designer's mind and the modelling medium. Interestingly, all of the drawings under the category 'recording ideas and decisions taken at meetings' were considered as sketches: a reflection that the drawings were produced after the meetings and were for personal use only. Only for the category 'explanations to colleagues' were all of the drawings considered as non-sketches, having formal characteristics that purposely facilitated communication to other people. Furthermore, if reference is made to the taxonomy of fifteen 2D product representations developed by Evans & Pei

(2010), it can be seen that the majority of drawings fell into the categories 'referential sketch', 'memory sketch', 'information sketch' or 'prescriptive sketch'. These drawing types mostly facilitate development and communication of technical considerations rather than attractiveness of form or interaction; given that all of the guitar drawings were related to materials and manufacturing, the use of these particular drawing types appears both apt and unsurprising.

As the polymer guitar ideas became more developed, there was a tendency away from sketching and freehand representation, towards a general increase in graphical definition and greater use of drawing instruments. Nevertheless, sketching is not somehow dropped once downstream product development is reached: it can be expected that sketches of manufacturing problems, marketing problems, revised design details and so forth will need to be made.

One notable feature of the drawings presented in the portfolio is the extensive use of annotations and textual explanation, even in sketches intended for personal use. Indeed, none of the drawings are absent of text. This of course is a matter of the personal style of individual designers. However, Dias et al. (1999) provide evidence that verbal articulation is a component of designing and that writing is complementary to, and fulfils a function not obtainable through, drawing. Furthermore, Doyle's (2004) article fully embraces text as a contributory language for technicity.

The five categories of drawings have not been tested for general applicability, but this might be something to consider for the future, for example by asking students to review their sketchbooks from the perspective of drawing use. Being based on retrospective analysis, the comments may be open to post-event rationalisation, but the task should nevertheless prove useful to reveal the extent to which purposes of drawings are shared among designers.

In order to reach conclusions from the work presented, it is helpful to revisit four modelling and graphicacy related curriculum review questions that were posed in Norman & Pedgley (2005:138), within the wider remit of nurturing technicity. It should be noted that these conclusions, if applied to a secondary education subject such as Design and Technology, could plausibly help to develop better graphicacy amongst the population at large and, thus, advantageously elevate the level of technicity possessed by next generations.

1. Is sufficient emphasis placed on the importance of language (drawing) in bringing stakeholders together?

It is crucial that design education does not lose sight of the vital nature of drawing and continues to develop curricula where students learn how to use drawing as a design tool as much as a communication tool. This especially applies to group working contexts, where sketches can be co-created and evaluated: ability to sketch is crucial for effective participation.

2. Are students encouraged to use drawing (or 2D and 3D modelling media) as an external memory system?

This point assumes the principle that students require cognitive skills (for capability in visualising something internally in the mind's eye) and practical skills (for capability in externalising mental imagery in modelling media). Development of both cognitive and practical skills should be encouraged, since they feed each other.

3. Are students taught to understand and develop drawing (modelling) strategies suited to their purposes?

In the author's experience, industrial design students do not properly exploit the dialogue between mind and media that is a characteristic of effective sketching and a valuable means to developing design ideas and generating new ones. Certainly it is a considerable challenge to 'teach' this dialogue.

4. Are students taught how to draw (model) appropriately using 'instruments'? For aspiring professional designers, 'instruments' are now most likely to be digital: use of a tablet PC and a freehand sketching programme for visualisations that can be directly utilised downstream in concept development processes; use of parametric CAD for easily edited and manipulated formal drawings.

In summary, each of the above points support Doyle's (2004) proposition that a technology of language, rather than a language of technology, can usefully underpin design education seeking to develop modelling, graphicacy and technicity.

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## A review of the nature, provision, and progression of graphical education in Ireland

*Niall Seery, Raymond Lynch, and Rónán Dunbar*

### Abstract

*This paper aims to review the evolution and status of graphical education in the Irish Second Level Education System. Through the review of relevant Irish educational documents and of apposite technical graphics syllabi, the significant developments that affected key curricular changes and resulted in the development and implementation of the current Design and Communication Graphics Syllabus (NCCA, 2007) at Senior Cycle are highlighted.*

*The paper presents a historic account of the systematic policies that shaped both the nature and provision of education in Ireland. The impact of the traditionally academic and vocational approaches to education as they converged to form a more comprehensive national second level curriculum is also discussed. This discussion emphasises how this convergence has affected the definition, perception and contribution of graphicacy within technological education.*

*A review of relevant literature and primary data collection methods were utilised to evidence the origin of graphical education as defined by technical and mechanical*

*draughting that historically aligned with vocational educational objectives. The paper consequently presents Design and Communication Graphics as a contemporary progressive syllabus that establishes graphical competency as the cornerstone of technological literacy and capability.*

*In conclusion the paper illustrates the intellectual heritage that has defined the traditional understanding of graphicacy. This heritage highlights the context, contribution and purpose of previous graphical education and lays the foundation for developing a more holistic and comprehensive understanding of the value and role of graphical education.*

### Introduction

The primary objective of the review is to outline the nature and provision of graphical education at second level. The paper will focus on the technical context of graphical education and the dichotomy of technical/mechanical graphics and broader graphical competencies.



Context – The provision of academic and vocational education in Ireland

Prompted by changing political and social values released by the French revolution and changing conceptions of childhood across Europe, many countries such as Switzerland, Holland, France, Spain, Greece, Italy, Denmark, Sweden and Norway all witnessed significant initiatives in the state's involvement in educational provision during the early 19th century (Murphy 1972; Coolahan 1981). However, Ireland under colonial rule was much slower to experience state involvement. Following the establishment of the Irish Free State in 1922 the first Department of Education was formed and formal provision of education was introduced (Dowling 1968). The Intermediate and Leaving Certificate were the state examinations offered almost exclusively to students who attended private secondary schools. Both were introduced in June 1924 under the Intermediate Education Act (Hyland and Milne 1992) and have continued since then as the founding framework for the examination of secondary education in Ireland. The Intermediate Certificate was a prerequisite to the Leaving Certificate and was completed by students at the end of a three year cycle. In order to pass the Intermediate Certificate Examination, students had to obtain a pass grade in at least five subjects. These subjects had to include the following categories: 1) Irish or English, 2) A second language other than Irish or English, 3) Mathematics (arithmetic for girls) with any one of the following Science, Domestic Science, Drawing, or Music, 4) History or Geography. To pass the Leaving Certificate students had also to pass at least five subjects in similar disciplines (Coolahan 1981). Of those students who sat the Intermediate Certificate examination, less than one-third would proceed to the Leaving Certificate. In 1925 the Leaving Certificate

examination was held at 149 centres around the country, beginning on the 16th of June and extending over 9 days (Department of Education 1926). The system was also dominated by male pupils and during the 1920s approximately 60 per cent more males than females were enrolled in secondary schools. Of the 1,058 students who sat the Leaving Certificate in 1929 only 313 (29.6%) were female.

By contrast vocational education differed in terms of its origin and provision. Vocational education in Ireland has traditionally had a lowly position in secondary level Irish schools (Dowling 1968). Technical education suffered from a lack of clarity as to what it involved and the methodologies and techniques that should have been employed. It was thought that the skills involved could be learned through formal apprenticeship and informal experience in the work place. Two landmark developments that specifically addressed vocational education in Ireland were the Agricultural and Technical Instruction (Ireland) Act of 1899 and the Vocational Education Act of 1930 (Trant, Branson et al. 1999).

The Agricultural and Technical Instruction (Ireland) Act of 1899 resulted in the formation of the Department of Agriculture and Technical Instruction which set out to develop technical education in Ireland. A significant failing of the act was the absence of financial provisions for the building of Technical schools. As a result prior to 1930 there mainly remained only two types of schools in Ireland, primary (elementary) and academic secondary, with a small number of technical schools in urban centres only. At first private or disused buildings such as old distilleries, hospitals and warehouses were converted for use as technical schools (Logan 1999). However, this development was primarily

based in urban areas, as in rural districts it proved to be, for the most, impractical. Most of the teaching performed was based on evening courses which imposed serious limitations on what could be achieved. It was not until the establishment of the Vocational Education Act of 1930 that directed vocational educational schools were developed.

The Act of 1930 replaced the technical instruction committees established under the act of 1899 with vocational education committees (VECs) and by 1936 had established forty-six new schools, extensions to twenty-one others and initiated building programmes for forty-eight other schools (Coolahan 1981; Logan 1999). However, at that time these vocational schools were not permitted to present students for either the Intermediate or Leaving Certificate Examinations. Students of vocational schools were required to sit the Day Vocational Certificate Examination, commonly, known as the Group Certificate examination which was introduced in 1947 and examined students in 'groups' of continuation subjects. The subject groups were; manual training, general commerce, secretarial commerce, domestic science, and rural science (Coolahan 1981). To pass in any subject group a student must pass certain obligatory subjects and one could add a number of optional subjects in a related area. By the end of the 1950 up to twenty different subjects were provided for by the Department of Education as part of the Group Certificate Curriculum but few schools offered every subject (Logan 1999). However, all schools offered the core subjects which included; Arithmetic, Commerce, Domestic Economy, English, Irish, Mechanical Drawing, Religion, Typewriting, and Woodwork. Less commonly available subjects such as Art, French or German tended to be offered only in larger urban schools (Logan 1999).

The aim of the Group Certificate Syllabus was the preparation of students for technical vocations and not for further academic development and progression. This was evident by the fact that vocational schools did not offer Latin, which at the time was a requisite under the matriculation system of most universities. Latin was offered only in secondary schools. Furthermore the basic vocational school course of two years in duration was distinctly shorter than the three year initial education cycle (Intermediate Certificate) offered by secondary schools. There was a clear delineation between the role of secondary education and that of vocational training.

### **Educational provision and integration**

In 1966 the state introduced the common Intermediate Course which was traditionally only offered by secondary schools. This led to vocational schools being allowed to present students for academic state examinations for the first time. This marked a shift in emphasis from vocational training to a more comprehensive curriculum within state supported schools. This amalgamation coupled with the attempts to address socio-economic needs, continued decline in the school going population and increasing financial difficulty resulted in the passage of Donagh O'Malley's Free Education Act in 1967 (Hyland and Milne 1992). This scheme was introduced to facilitate the provision of second level education for all young people.

The changing role of technical schools, coupled with free education dramatically changed the face of Irish Second Level Education. On completion of the Vocational Group Certificate, which traditionally led to apprenticeship training and entry into the Junior and Senior Trade Examinations, pupils of vocational schools

for the first time could progress to acquiring academic qualification. This broadened the focus of vocational schools and coincided with teachers of practical subjects no longer being referred to as manual instructors but teachers. The egalitarian movement resulted in less definitive educational outcomes which was traditionally governed by the type of school attended. This changed the nature of teaching and learning and called for the revision and creation of a range of technical curricula. The need to create Leaving Certificate technical subjects that were comparable to the classical academic subjects challenged the nature of technical education. The first leaving Certificate technical subjects; Engineering Workshop Theory and Practice, Building Construction and Technical drawing were introduced in 1969 and examined at a common level in 1971. Figure 1 below illustrates the nature and convergence of graphical education towards general education objectives.

### Graphical education

The lack of comprehension surrounding the intellectual heritage that shapes contemporary norms and practices within graphical education facilitates a dependence on a hegemonic culture. This culture protects the dominant practices (McCormick and Davidson 2009) hindering progression and limiting the capacity to establish a rationale for change. As in many countries, graphical education has its origin in two delineated and apparently unrelated threads of education; Art education and technical education. Within the context of the established levels of attainment, it is important to present the nature and provision of graphical education with particular emphasis on technological capability.

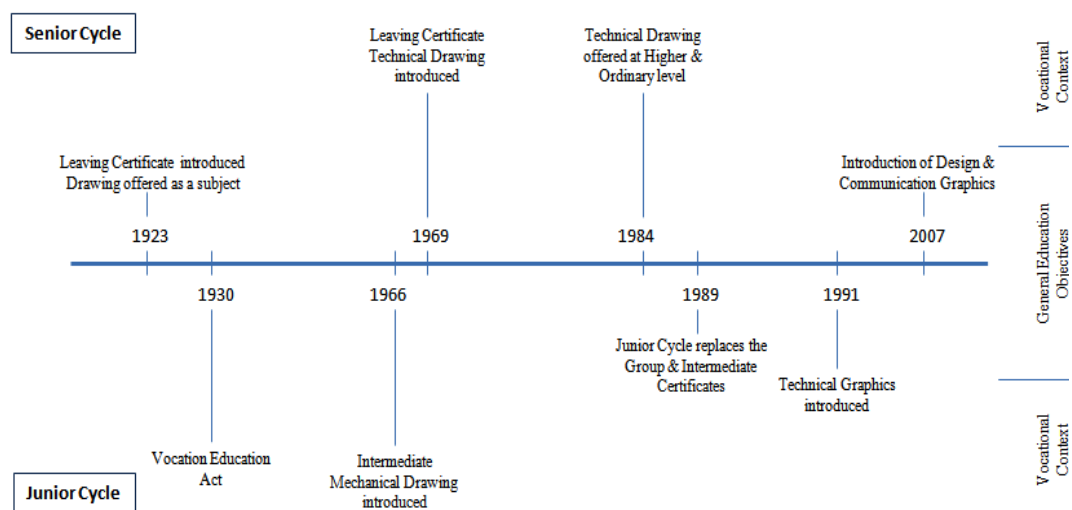


Figure 1 – Developments that changed the nature and provision of graphical education

**Junior Cycle**

Vocational education is grounded in a utilitarian philosophy and Mechanical Drawing from its inception in 1936, had a direct and purposeful relationship between the craft based education of wood and metal working. The nature of Mechanical Drawing was to develop communication and interpretation skills associated predominantly with manufacturing and craft based outcomes. Housed in the context of manual training, Mechanical Drawing focused on the production of well draughted drawings that utilised knowledge of projection systems, plane geometries and standards and conventions that supported the effective communication of typical craft based

outcomes. Drawings tended to depict applied problems such as woodwork joints and sheet metalwork artefacts (Figure 2) and typically produced outcomes aligned distinctly with purposeful communications that were transferable into the workshop.

In the early stages of Mechanical Drawing, one inclusion in the examination at Group Certificate level was freehand sketching, where sample miniature industrial castings (approximately 3 inches in height) were posted to the school. Pupils were required to make freehand sketches of the principal orthographic views and a pictorially viewed image. One commentator (Lee, 2011) postulates that this practice and element of the Group Certificate Examination was discontinued due to the cost of production

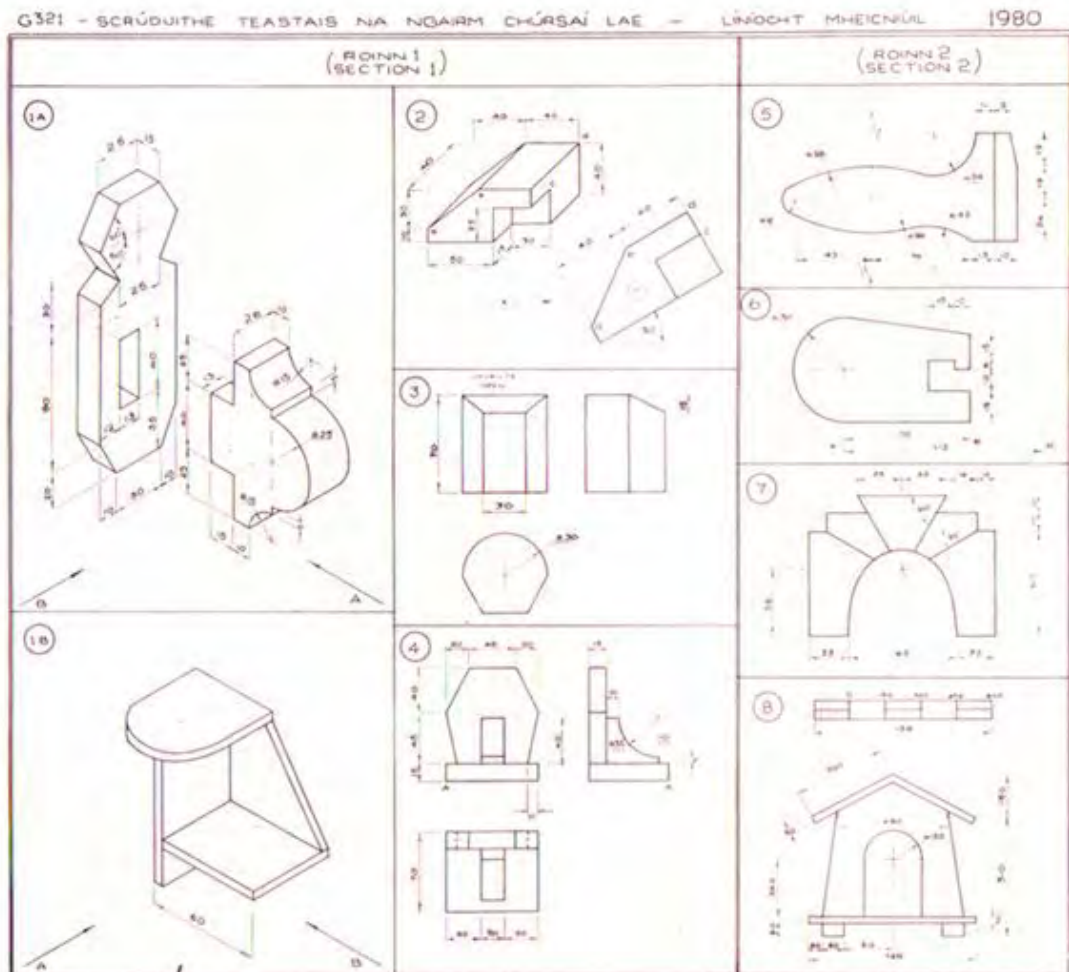


Figure 2 – Example of a Day Vocational Examination (Group Certificate)

and postage. The discontinuance of sketching as an examinable skill (even if only observational in nature), gives a significant insight into the nature and purpose of the subject at that time and clearly defined the main focus as technical draughtsmanship.

In parallel to the Group Certificate, the Intermediate Certificate subject, Mechanical Drawing, was examined from 1971 to 1993. The amalgamation of academic and technical education brought with it a number of societal and educational complexities. Even though mechanical drawing was now offered outside the technical schools, it still maintained its vocational heritage. At both levels, Mechanical Drawing valued the development of technical draughting and emphasised skills rooted in vocational objectives. Initially the distribution of marks in the terminal assessment centred on technical draughtsmanship, with 40% of marks per question awarded for draughtsmanship, neatness, arrangement and presentation. The following example of the guidelines given to teachers indicates the technical focus of the activities; "The most satisfactory method of correcting a large number of drawings is to draw an accurate solution of each problem set and then take an accurate ink tracing on tracing paper" (Parkinson, 1977: 250). O'Luasaigh (1977: v) outlines the features he took into account when designing his Intermediate Certificate textbook as;

- Each lesson is presented in the form of a specimen drawing sheet
- The pages closely resemble the student's work
- Each sheet is a complete unit in itself
- Dimensions are suited to A3 which are in the same proportion as the student's drawing sheet

This reflects the technical nature of the subject and is suggestive of didactic instruction being both the dominant and acceptable pedagogical paradigm.

The morphing of technical education into a general education caused many complexities. The perception of a subject with a lowly, non-academic status coupled with the perception of a diverging range of pupil abilities manifested in blurring both the purpose and objectives of graphical education. Parkinson (1977) presented a section in his Intermediate Certificate Textbook entitled "Technical Drawing for Slow Learners" (p. 250), advising teachers to keep material in the concrete while placing less emphasis

on formal geometry and concentration placed on any area where quick, surprising results are obtained, i.e. ellipse by pin and string methods, development of surfaces resulting in the cutting out of models and their developments and completion with sellotape, possibly to a large scale. (p. 250)

Much of the amalgamation embodied the cultural perception that there was a two tier educational system. The coming to terms with the perceived transition from technical education to academia is echoed by Clark (1976) as he outlined in the preface of his Intermediate Certificate textbook;

(The drawings were designed) to suit the needs of the weaker as well as the more gifted student, care has been taken in the grading and selecting of the problems and as many of them as possible have been divided into two or more parts to allow this. (p. 6)

The well-defined vocational role of Mechanical Drawing had shifted in focus, highlighting an uncomfortable transition from vocational to academic learning.

The Junior Certificate was introduced in 1989 proposing a significant change in educational philosophy, embracing a more pupil centred approach to learning with emphasis on active learning. The Junior Cycle Examination replaced the Day Vocational (Group) Certificate and the Intermediate Certificate in 1992 and offered two levels of study 'Higher' and 'Ordinary' for the first time in technical education. This new qualification is placed on the National Framework of Qualifications at Level 3. Although, many new syllabi were introduced to coincide with the new Junior Cycle it was not until 1991 that Technical Graphics replaced Mechanical Drawing. This offset in implementation combined with a lack of professional development hampered the potential offered by a new syllabus that fostered a broader conception of graphicacy. Technical Graphics proposed the "development of the cognitive and practical manipulative skills associated with graphicacy" and "to stimulate the pupils creative imagination through developing their visuo-spatial abilities" (NCCA 1991:5.) while promoting communication of ideas, graphical problem solving, CAD competency and exploration of graphical concepts and principles through the medium of modelling. The lack of support for practicing teachers resulted in practices that resembled the previous delivery of Mechanical Drawing, achieving new outcomes in old ways and rendering change somewhat benign. The broader goals were lost in a traditional value system.

The discrepancy between origin and purpose of Technical Graphics is more apparent within the Senior Cycle programme of study, commonly known as the Leaving Certificate.

### **Senior Cycle - Leaving Certificate from 1925**

The established Leaving Certificate was first introduced in 1923/24. One of the subjects assessed as part of the Leaving Certificate at this time was Art and Drawing, within which was the area of Mechanical Drawing and Design which was worth 100 marks out of a possible 400 marks. This was a common level paper as the only subjects to be examined at both a 'Higher' and 'Ordinary' level at this time were English, Irish and Mathematics. As shown in Appendix A the examination paper was further subdivided into two sections. Students had the option of taking Section 1 which focused primarily on what was referred to as design or Section 2 which centred on mechanical drawing. Drawing within this Leaving Certificate context focused primarily on observational drawing with students studying elements such as Mechanical Drawing and Design as well as:

- Object and Memory Drawing
  - Drawing from Natural Form
  - Pictorial Design
  - Modelled Design
  - Drawing from Life
  - Painting from Life
- (Department of Education 1941)

In the 1920 only students who attended secondary schools could sit the Leaving Certificate with almost twice as many males than females sitting the Leaving Certificate Examination. For example in 1925, a total of 3,898 sat an examination as part of the Leaving Certificate, of which 2,586 were male and 1,312 (33.7%) were female. In this year 108 males sat Drawing for the Leaving Certificate with an 84.2% pass rate compared to 32 (22.9%) females sitting the same examination with a pass rate of 87.5%. This represented a 4.2% uptake of males and 2.4% of females

for the subject in this year. When adjusted for gender distribution, in 1925 there was a 36% participation of female students studying Drawing. The parity in distribution of gender infers the nature of the subject as having a general educational purpose and value and not defined as a specific end in itself.

The Technical Drawing syllabus for the Leaving Certificate was first introduced in 1969 only three years after the alignment of vocational and secondary schools. By 1969 vocational students would have completed three years of the intermediate certificate and progressed to the Senior Cycle. The first students sat the Technical Drawing examination in 1971. This replaced the former drawing examination that students previously sat as part of Art and Drawing, the last examination for which was in 1970. Both the relevant section of the 1970 Art and Drawing examination, and the 1971 Technical Drawing examination are included as Appendix A and B respectively, for comparative purposes. The introduction of the Technical Drawing syllabus represented a significant shift in focus from observational drawing to more mechanical and technical drawing. In the same year the Engineering Workshop Theory and Practice, and Building Construction syllabuses were also introduced. The new syllabus was designed to complement this shift toward the inclusion of technical subjects as part of a more comprehensive curriculum and as a result, for the first time the subject was divided into two separate optional areas under which students could be examined. All students of the subject were examined in what was referred to as core elements (Plane and Solid Geometry) as part of paper 1 in the examination but could choose to sit Option (A) Engineering Application, or Option (B) Building Applications as part of paper 2. This was the first time such distinction between

these two areas of the subject was made in the state examinations and was offered at a common level. Students continued to sit a common level paper for Technical Drawing until 1984 when for the first time students were offered the option of taking the examination at either 'Higher' or 'Ordinary' level for the Leaving Certificate.

The introduction of the Technical Drawing syllabus in 1969, also represented a clear shift in focus from the applied nature of Mechanical Drawing and Design to a more abstract and technical syllabus. For example, as shown in Appendix A, questions from the 1970 Mechanical Drawing and Design paper concentrated on applications such as the creation of a 'lamp shade' (Question 1, Section 2), or the creation of a 'tile' design (Question 5, Section 3). By comparison the 1971 Technical Drawing paper shown in Appendix B, focuses more on abstract problems such as the construction of a parabola given limited information (Question 1) or the completion of two intersecting oblique planes and determining the dihedral angle between them (Question 4). The inclusion of abstract problems in the Technical Drawing syllabus helped to elevate the academic status of the technical subjects now that they were assessed by state examinations within secondary and vocational schools. A more 'academic' syllabus was achieved by the inclusion of what can be described as 'Abstractions' (Lee, 2011). Lee (2011) highlights the example of Catenary where the abstract concept is intellectually challenging, but serves no relevant practical application. Commentators have referred to this as the "gentrification" of the technical subjects and argue that policy makers should defend technical education on merit alone. One hypothesis for the development and inclusion of 'Abstractions' in the Technical Drawing syllabus may be that the lack of

an industrial revolution in Ireland facilitated the shift from applied geometry and applications to more intellectually challenging content that in some incidences lacked relevant meaning. Ensuring a comparable technical syllabus for the Leaving Certificate should have increased the complexity of the applied problems instead of changing the focus to abstract concepts. The importance of enabling pupils to create meaningful innovation as opposed to learning the rules to produce abstraction, independent of meaning, is the objective of contemporary education. Pupils who can neatly construct, present and arrange something that is meaningless or independent of comprehension is a meritless exercise. Furthermore, adopting a mechanistic rote approach to learning becomes more of a necessity than option when the application and transferability of new knowledge is removed from practicality.

The Technical Drawing syllabus was recently replaced in 2007 with the Design and Communication Graphics syllabus.

A new conception of graphical education Design and Communication Graphics (DCG) was introduced as a Leaving

Certificate subject in September 2007 and was assessed in the Leaving Certificate Examination for the first time in June 2009. It exists as one of four new and revised subjects within the proposed suite of technological subjects that contribute to a broad, balanced and general education of students (NCCA, 2007). The accompanying subjects include Engineering Technology, Architectural Technology and Technology. These four subjects were intended to replace the previous three technological subjects; namely Engineering, Construction Studies and Technical Drawing.

The content of the new DCG syllabus is still evidently aligned with its companion technological subjects where topics such as Dynamic Mechanisms, Structural Forms, Geologic and Surface Geometry and Assemblies form the Applied Graphics area of study. However a number of notable shifts took place when this new subject replaced its predecessor, Technical Drawing. The new syllabus structure (Figure 3) focuses on a design driven approach where students develop skills in graphicacy, creative problem solving, spatial abilities and design capabilities to prepare them to be creative

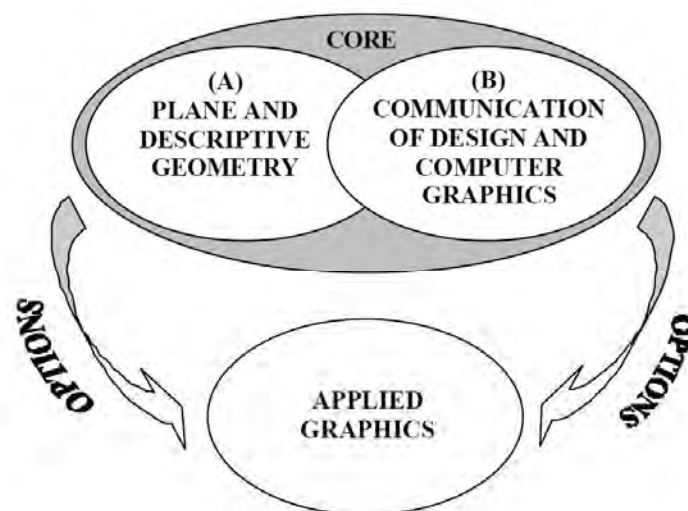


Figure 3. Design & Communication Graphics Syllabus Structure



participants in a technological world (NCCA, 2007) and gives equal emphasis to both Plane and Descriptive Geometry and Design and Communication within its core.

The Introduction and Rationale included in the subject syllabus document outlines that the body of knowledge associated with the Plane and Descriptive Geometry section allows students to explore a number of applications associated with design. The main focus of the Applied Graphics section of the syllabus is to afford students the opportunity to explore the principles of plane and descriptive geometries through non-discipline specific practical application (NCCA, 2007). Even at higher level where the traditional treatment became abstract the DCG syllabus promotes a comparable level of attainment in a more concrete and applied context (Appendix 3).

This shift in focus from the traditional prescribed drafting to a more autonomous and innovative engagement necessitated a shift from the sole reliance on terminal assessment. The assessment of DCG consists of a terminal examination and practical coursework in the form of a student assignment, which are worth 60% and 40% of the allocated marks respectively. The inclusion of the practical coursework was one of the substantial adjustments made to the subject. This element of the assessment requires candidates to carry out a design investigation in response to a thematic brief issued and marked by the State Examinations Committee. The design theme, which permeates the course, will empower the students to communicate their design ideas and solutions with accuracy, flair and confidence (NCCA 2007, p1.). A compulsory part of this assignment is the use of parametric modelling software (Solidworks). Other elements of the assignment require

students to explore the physical geometry of existing artefacts. Students are encouraged to use a variety of techniques including freehand sketching, rendering and available computer applications (Photoshop, Microsoft Publisher, Microsoft Word, Photorealistic Images, etc.) to effectively communicate their findings through graphical communication. This is in contrast to the vocational origin of the subject.

Supporting a new syllabus and a new assessment model necessitates significant state investment. The failings of Technical Graphics to reach its potential when introduced at Junior Cycle were directly related to the low level of in-service and support provided to practicing teachers. To ensure the successful implementation of a new conception of Graphical education within the suite of technological subjects the technology Subject Support Service was founded. The mission statement of this support service was to empower and support teachers in providing creative and inspiring learning experiences for students ([www.t4.ie](http://www.t4.ie)). A full time team was established, consisting of 12 members; A National Co-ordinator, an Assistant National Co-ordinator for each of the subjects and five Regional Development Officers for Design and Communication Graphics and two for Technology. A part-time team of 47 associate trainers was also formed to contribute to the creation of resources and deliver the in-service training days.

The complete team of associate trainers were themselves teachers of the technology subjects, as the T4 aimed to provide a service that focused on 'teachers, teaching teachers' which became an anecdotal motto of the association. This helped to ensure that the people behind the change and reform of the technology subject areas were key

stakeholders themselves to avoid a failing in-service programme due to top down reform. Substantial funding of €25 million and effectual contemporary resources led to a very successful in-service programme where the levels of attendance and participation were unparalleled in any other subject area. This gave a clear indication that the failings associated with the implementation of previous technological subjects were not repeated (McGuinness, et al 1997).

The in-service was offered over 13 rounds. The first round of in-service was in September 2006, one year before the subject was initialised in schools. The first nine rounds were delivered during the 'intensive phase', which was completed in March 2009, before the first formal assessment of the subject in June of that year. Each round focused on a particular area of the syllabus and a complete set of pedagogical resources were developed and administered to the teachers. Emphasis was placed on the approach taken to teaching the new subject matter where an 'integrated and applied approach' was reiterated during all sessions. Continuous feedback and analysis of teachers' perceptions of the new course were recorded to ensure that the objectives of the support service were being achieved. The training teachers were also encouraged to comment on the approaches being implemented to ensure that they had a sense of ownership of the new subject area.

An overwhelming positive response was noted following all rounds without exception, and continuous support and praise was offered from the Department of Education as a result of the success of the in-service. Teachers' responses to the in-service led to additional training through other organisations in conjunction with the T4 who continued to steer the philosophy

of the new subject. The National Council for Technology Education (NCTE) and the Teachers Professional Network (TPN) offered additional training for teachers which were strongly attended, especially in comparison to other teacher professional development courses previously ran out of school time. This displayed how the teachers were taking ownership of the new subject and were realising the importance of their contributions as the pedagogical drivers of the new syllabus.

### **Current status of Design and Communication Graphics**

Design and Communication Graphics was first examined in 2009 with 5,485 (10.8% of the entire cohort) sitting the Leaving Certificate Examination. The approximate 11% uptake is generally consistent with annual statistics from 2004 to 2010. However, there was a marked shift in the numbers of candidates sitting the higher level examination. A mean of 54.3% (SD 1.5%) was recorded from 2004 to 2008, this increased to 66.2% taking the higher level paper in 2009, and was maintained in 2010 (69%). For the initial examination an additional 250 pupils completed the higher level design brief assignment and then chose to take the ordinary level paper on the day of the examination. This increased engagement in the higher level subject resulted in a noticeable decrease in A grades awarded at ordinary level from between 11% and 12.5% in 2007 and 2008 respectively to 6.6% in 2009. The overall standard at higher level was reported as very high in both the project assignment and terminal assessment. The higher level performance across the A, B and C grades was slightly higher than previous years, with a slight reduction in A grades. This is commonly observed with the introduction of a project element into the assessment model.

With regard to gender distribution, there was a consistent upward trend in female participation, increasing from 7% in 2005 to 9% in 2009 and 11% in 2010. At ordinary level, there was no significant difference in performance between male and female candidates; however female pupils did achieve a higher percentage (8.0% compared to 6.5%) of A grades than male pupils and a lower failure rate, this is generally consistent with past observations. At higher level female candidates tended to out perform males across the entire grade spectrum and again this is consistent with comparisons to performance in Technical Drawing.

The Chief Examiners report (2009) highlights the shift in focus of the terminal examination to reward “critical thinking and problem solving skills” as a result candidates that produced ‘rote’ style answers in general did not achieve the higher grades. It was also encouraging to note that there was less dependence on a ‘rote’ approach by comparison to Technical Drawing.

The report outlined the standard of performance in the design brief as generally good. Candidates completed a design brief that included a choice between making design modifications to an existing product/artefact and developing a conceptual solution. Four out of every five candidates opted for the design modification, with candidates who choose the conceptual design approach generally performing better. Solutions to the modification exercise were often described as “over simplistic and superficial”. In general the initial research and investigation stage of the development tended to be weak and one dimensional. This aligns with the deficiencies noted with the standard of sketching presented within the conceptual and modifications element of the design brief by comparison to the

graphical representation section. It was reported that although some candidates produced excellent freehand presentation drawings there is a need to further “emphasise, develop, and promote” sketching capability.

### **Concluding comments – the future of graphical education**

The outlined account of graphical education has lead to the realisation that the historic evolution of the Irish education system has greatly impacted on the nature of the subject area. Technical Drawing and Communication Graphics have evolved through the decades of the 20th Century, with major developments coinciding with a number of key shifts in how education was being offered in Irish second level schools. As a result, the nature and provision of graphical education has taken a number of shifts in emphasis, with Technical Graphics at Junior Cycle and Design and Communication graphics at Senior Cycle drawing upon traditional values whilst fostering contemporary approaches to the subject area.

The introduction of Technical Graphics at Junior Certificate level in 1991 gives an apparent indication that policy makers looked beyond the vocational objectives of graphical education. Despite the complexities and context surrounding the implementation of the syllabus, a broader conception of graphical education was envisaged, highlighting the value of a subject that developed a more general human capacity. However, this becomes problematic when the dichotomy between the prior experiences and perceptions of practicing teachers do not constructively align with the intended holistic educational aims of the syllabuses (Mittell and Penny, 1997).

The successful implementation of Design and Communication Graphics (2007) has made a significant contribution to the development of graphical capability and literacy. In many ways it has strengthened the position of Technical Graphics by embracing a broader conception of graphicacy. The philosophical shift from a prescribed vocationally grounded subject to a subject that embraces design driven competencies questions the nature of design and its relationship with graphicacy. The review presents evidence that graphicacy is regarded both as a general human capability and as an integral part of designing. There is variance in perspective as to whether designing is a general human capability, or a vocationally grounded subject, or even perhaps both. Valuing broad education objectives within technological education necessitates a defining of this context.

Encouraging freedom of expression, individual heuristics, and divergent thinking requires an exploration into the definition of domain specific knowledge. Defining subject content knowledge that is now appropriate and more importantly establishing the ownership of this knowledge, requires educationalists “to adopt a new conception of human ecology, one in which we start to reconstitute our concept of the richness in human capacity” (Robinson, 2006). Defining the purpose and meaning of content in relation to the importance of personal development and within the context of broader educational objectives is the fundamental challenge.

Understanding the heritage that dictates educational practice enables critique, and informs the essence of teaching and learning. At the core graphical education remains a communication language, the nature of this communication has developed from predefined draughting to the inclusion of ideation, synthesis, and

innovation, where pupils are afforded the opportunity to explore conceptual design and communicate their glimpse of the future. Therefore knowing what to teach is now more critical than ever in ensuring we develop a comprehensive understanding of the role and value of graphical education. Subordinate to defining what constitutes this widening discipline is appropriate pedagogical practice; an auxiliary research agenda.

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# Appendix A

AN ROINN OIDEACHAIS  
LEAVING CERTIFICATE EXAMINATION, 1970  
ART AND DRAWING

MECHANICAL DRAWING AND DESIGN  
Honours

MONDAY, 22nd JUNE - MORNING, 9.30 to 11.30

M. 92

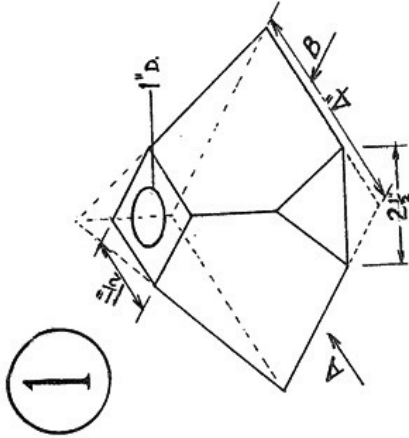
5. Draw with lettering pen, pens, or brush, the title page for a book. The lettering is as follows:-

FRANCIS BACON

Selections  
With Essays by Macaulay & S. R. Gardiner,  
Edited by P.E. & E.F. Matheson  
Oxford

At THE CLARENDON PRESS.

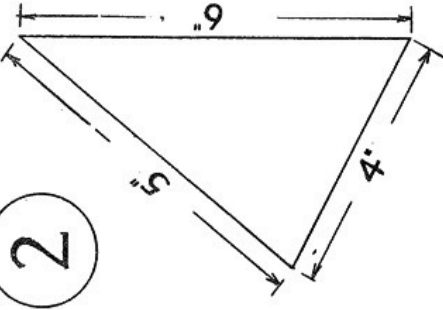
The size of the page should be not less than  $7\frac{1}{2}$ " x 5".



## SECTION II - (100 marks)

THREE QUESTIONS ONLY TO BE ATTEMPTED  
(All questions carry equal marks)

\*1. The diagram shows a small lamp-shade. It is formed from a truncated right square pyramid  $4$ " high to apex perpendicular height, with one corner cut away vertically from the base. Draw a front elevation in the direction of the arrow A, and an end elevation in the direction of the arrow B, and a plan. Draw a complete development of the lamp-shade.



\*2. Draw the triangle shown in the diagram according to the dimensions given. Show by construction how you would draw the largest possible circle within this triangle. Dimension the diameter of the circle.

\*3. The development of a scoop is shown in the diagram. Draw a front elevation an end elevation and a plan of the completely folded scoop according to the dimensions given.

\*4. The diagram shows details of a funnel. Draw a front elevation, in the direction of arrow A, an end elevation in the direction of arrow B, and a plan. The flat plane X is parallel to the axis.

5. Seven hexagonal tiles of  $1\frac{1}{2}$ " sides are placed edge to edge to form a central pattern on a circular tray. A plain border  $\frac{3}{4}$ " wide is then drawn around this design to complete the tray. Draw a plan full size.

## INSTRUCTIONS

- Candidates may take Section I or Section II but not both.
- The use of drawing instruments and tracing paper is allowed. Printing and pattern making materials may be used.
- The number of the question must be distinctly marked by the side of the answer.
- Questions marked (\*) have accompanying diagrams.

## SECTION I - (100 marks)

ONE QUESTION ONLY TO BE ATTEMPTED

- Design a poster for one of the following:-  
Design Centre; Music Festival; Join the Army.  
Include such lettering as you consider appropriate. Work as large as possible.
- Within a rectangle  $14$ " x  $9$ " make an abstract composition suitable for execution in a craft. Your design should be based on one of the following:  
Spring; Solemn Music; Flight; Woodland.
- Make a colourful pattern suitable for a fancy wrapping paper or a girl's dress material. Use any suitable technique. Complete as much as possible.
- Design a cover for any book you have read. The design should be not less than  $9$ " x  $7$ " and suitable for execution as a lino-cut, screen print or with stencils.

## Appendix B

A N R O I N N O I D E A C H A I S

M.117

LEAVING CERTIFICATE EXAMINATION, 1971

TECHNICAL DRAWING - COMMON LEVEL - PAPER I  
(Plane and Solid Geometry)

TUESDAY, 22nd JUNE - Morning, 9.30 to 12

### INSTRUCTIONS

- (a) Answer four questions.
- (b) All questions carry equal marks.
- (c) Construction lines must be shown on all solutions.
- (d) Write the number of the question distinctly on the answer paper.
- (e) Candidates working in metric units should write the letter "M" distinctly beside the number of the question on the answer paper.
- (f) All dimensions on the question paper are given in millimetres, with inches in parenthesis.

1. The focus F and the directrix DD' of a parabola are given in Fig. 1. The position of a point P on the axis is also shown.

- (a) Construct the parabola to the given dimensions and erect a perpendicular to the line of the axis at point P.
- (b) Draw a tangent to the parabola at the point where the perpendicular line meets the curve.

2. In Fig. 2, the bars RH and AH are hinged at H and RH is pivoted at R.  
Draw the locus of the point P as the end of the bar AH moves from A to B.

Scale: full size

3. The incomplete plan and elevation in Fig. 3 shows the projections of a hemisphere penetrated vertically by a cylinder and horizontally by a square prism.  
Complete the plan and elevation to the given dimensions showing clearly the lines of intersection.

4. The traces of two oblique planes V.T.H and V'.T'.H' are shown in Fig. 4.  
Draw the traces to the given dimensions and show:-

- (a) the projections of the line of intersection,
- (b) the true length of the line of intersection, and
- (c) the angle between the planes,

5. The projections of a pentagonal pyramid are shown at Fig. 5. The pyramid is cut by the inclined planes AB and BC.  
Develop the surfaces of the pyramid below the cutting planes and draw the true shape of the cut surfaces.

6. The elevation of a cylinder is shown at Fig. 6. Two lines are scribed about the surface of the cylinder rising uniformly from points A'B' to points AB in one complete revolution.  
To the given dimensions draw the elevation of the cylinder showing the two lines in position.

7. The diameters of three spheres A, B and C, are 70, 50 and 40 millimetres ( $2\frac{7}{8}$ , 2 and  $1\frac{5}{8}$  inches), respectively.

## Appendix C

### Structural Forms

C-2. The 3D graphic on the right shows a ladies hat, which is in the form of a hyperbolic paraboloid.

The projections of the hat are shown in Fig. C-2 below. The perimeter is an ellipse in plan and the outline shape of the hat is formed by extending the hyperbolic paraboloid surface ABCD.



- Draw the outline plan and elevation of the hat.  
(The hole, which is circular in plan, may be ignored for this part of the question.)
- Draw the plan and elevation of the hole.
- A plane director for the elements AD and BC is positioned so that it contains the point B. Draw the traces for this plane director.

Scale 1:5

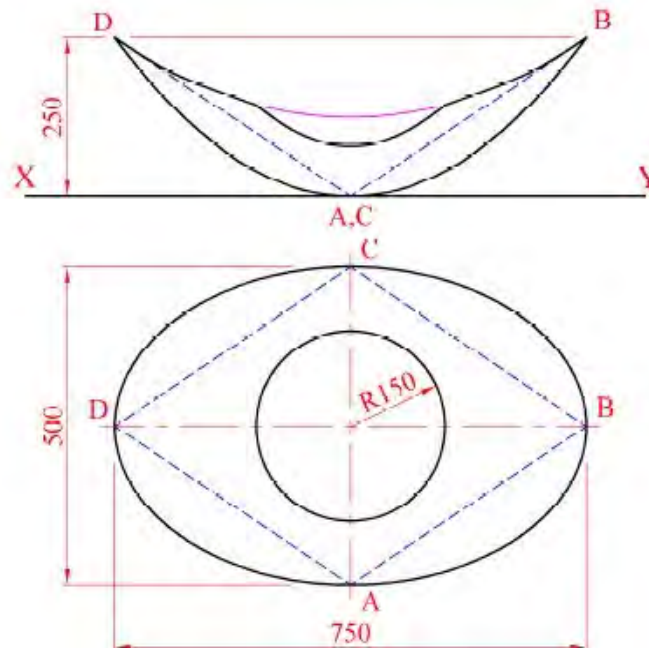


Fig. C-2





## **'Blurring the boundaries' - a metaphor to guide the development of specialist learning spaces as part of an academy design development project**

*Donna Trebell*

### **Abstract**

*The purpose of the study reported here was to investigate the iterative design development of a scheme which enabled the realisation of a forward thinking vision for specialist learning spaces, namely: Art, Design and Technology and Science informed by the metaphor 'blurring the boundaries'. This study focuses on the research question: How does the metaphor 'blurring the boundaries' inform the architectural design of specialist learning spaces in this context? A case study approach bounded by time and focus group was adopted (Cresswell, 1998). This approach was adopted in order to create a rich picture of the social setting and to illustrate the complexity of design development in this context.*

*Findings illustrate that an integrated approach encapsulating educational, architectural, information communication technology, mechanical and electrical and furniture, fittings and equipment inputs into the design development of the specialist learning spaces is a key feature in the journey from vision, through interpretation to reality in this context.*

### **Introduction**

During the life of the Building Schools for the Future and Academies (BSF) programme in the UK, schools were encouraged to re-think their approach to educational spaces in order to ensure that the needs of 21st century learners could be met. When the labour government were in power, this meant focussing on transformational change. This means 'changes in approaches to learning, teaching practices, relationships and school organisation' (Rudd, 2008: 6) in an attempt to move from "learned institutions' to the development of 'learning communities' where what is learnt, by whom, when, who, with and how becomes more fluid, emergent and evolves based on need and opportunity' (Rudd, 2008: 6). This philosophy has led to the development of a range of highly bespoke proposals such as the Knowsley City Learning Centres and New Line Learning Plazas each of which challenges the conventional school typology in favour of a forward thinking paradigm.

In the case of the Academy forming the focus for this study, the initial outline

business case was developed with transformational change in mind. At the time the Academy was part of the national challenge programme and therefore under scrutiny in terms of performance, including the need for more than 30% of students to gain five A\*-C grades including English and Maths. There was also a new Principal in post who had to work hard in order to balance the immediate requirement to raise standards, with the need to strongly guide the design development of both the outline business case and later the invitation to tender schemes. Together these responsibilities posed a considerable challenge in terms of time and energy.

Why 'blurring the boundaries' is a powerful metaphor in this context

Drawing from a number of sources (Pitt, 2009; Aston and Jackson, 2009), but ably illustrated by the 'Did you know?' presentation produced by Karl Fisch (2006) in order to challenge teachers within his school to re-think the curriculum offer in order to make it more relevant, we cannot escape the fact that the United Kingdom is a very small part of a global economy. And that in the global economy countries like China and India have more gifted students, than we have students. This means that educators in the United Kingdom have to work very hard in order to ensure that aspiring industry leaders of the future are capable of global competitiveness.

In addition to this we are living in a technological landscape which shapes our lives by introducing constant change. This means that it is highly likely that the students of today will have to adapt through multiple career paths during their working life. In summary 'we are currently preparing young people for jobs that don't yet exist, and technologies that haven't been invented, to solve problems we don't even know are problems yet' (Richard

Riley – Education Secretary under Clinton). With this in mind the development of skills such as the ability to think creatively, be reflective, able to perform independently and as part of a team alongside the acquisition of knowledge will be extremely important.

It should also be born in mind that through the secondary curriculum (DCFS, 2007) teachers have been encouraged to explore the links between subjects and to use cross curricular projects as a vehicle to explore realistic learning. The most prominent manifestation of this is the STEM programme which offers a range of support to teachers and students of science, design and technology, engineering and maths with a view to encouraging take up of these subjects at advanced level and beyond. Taken together this is beginning to encourage us to 'blur the boundaries' in an educational context in order to present more realistic learning opportunities. In the case of the academy which forms the focus of this paper 'blurring the boundaries' has become a metaphor to inform the architectural design of specialist learning spaces.

The purpose of the study reported here was to investigate the iterative design development of a scheme which enabled the realisation of a forward thinking vision for specialist learning spaces, namely: Art, Design and Technology and Science informed by the metaphor 'blurring the boundaries'. This study focuses on the research question: How does the metaphor 'blurring the boundaries' inform the architectural design of specialist learning spaces in this context?

As the complexity of this element of the education brief posed a challenge to the design team, it was vital that they worked collaboratively to develop an appropriate

solution. According to John-Steiner (2000:3) 'Generative ideas emerge from joint thinking with the interdependence of thinking leading to the co-construction of knowledge' and 'mutual appropriation of concepts' (John-Steiner, 2000:3).

This paper will be in four parts. First, it will review a breadth of literature relating to educational transformation, learning led design and pedagogy and space (Burgin, 1996; Fisher, 2006; Nair & Gehling, 2009; New London Group, 1996; Oblinger, 2006; Rudd, 2008; Thorn, 1999; Van Note Chism, 2006). Second, the paper will present and analyse the data. Third, the paper will discuss the significance of the results. In the conclusion suggestions will be made for further research to build on and extend the findings of this study.

## Literature review

### Educational transformation

During recent years, across a number of countries including America, Sweden, Australia and England there has been a focus on securing educational transformation as key part of the architectural re-generation of learning facilities. This challenge comes about in recognition of the fact that the 21st century learner is growing up in a 'knowledge economy' which demands a totally different skills set to that of the traditional 'industrial economy'. According to architect Prakash Nair (2009: 27), 'the industrial economy model manifests itself in the form of the classroom and corridor ('cells and bells') school design model that assumes all students will be doing the same thing, at the same time, using the same resources', in other words a 'factory model' which is a common starting point for most schools as it reflects the era in which the building was constructed. However, according to Puttnam (2008: 2), 'it is vitally important

.....that we seize the opportunity (through the design and build programme) to innovate and drive forward learning experiences in keeping with the needs of the future, reflecting the skills, competencies and needs of the wider society, our local communities and the changing nature of society in response to the global opportunities and challenges we face'. In doing so it has become increasingly important to develop a new architectural typology for school design which favours the provision of a wide range of different types of space which have the capacity to support diverse learning needs. Added to this as Torin (2002:1) points out is the fact that 'all of these spaces have to be designed to support the convergence of educational space and information technology' in order to embed educational practice within larger global flows of information and capital. Torin (2002: 1-2), also points out that recent aims are further supported by the concept of flexibility which in his work has been expanded beyond a traditional architectural understanding to include the following properties of space: fluidity, versatility, convertibility, scalability and modifiability. Fluidity manifests itself in open spaces which support the flow of individuals, sight, sound and air. Versatility is achieved through spaces that support multi-use such as cafeterias and auditoriums. Convertibility relates to the ease with which a space can be adapted for new use to support changes in enrolment, curriculum and pedagogy. Scalability is the ability of the space to expand or contract and modifiability is where the space invites active manipulation and appropriation through the use of partitions, furniture and equipment.

In response to these drivers school leaders have had to prepare educational vision statements which were designed to be used to inform the design process, leading

to the development of an education design brief and detailed outline business case. Through this process schools have had the opportunity to totally re-think approaches to learning, teaching practices, relationships and school organisation.

### **Learning led design**

Drawing on literature we know that 'space – whether physical or virtual can have an impact on learning. It can bring people together; it can encourage exploration, collaboration, and discussion. Or, space can carry an unspoken message of silence and disconnectedness' (Oblinger, 2006:12). What is less well understood is the extent to which space can be designed in order to create environments that through their anatomy and adjacency strongly support curriculum development.

Education research currently favours an approach which values the co-construction of knowledge through interaction (Vygotsky, 1978, 1981, 1986, 1987; Wegerif & Mercer (2000); Wertsch, 1991; Wertsch, Tulviste, & Hagstrom 1993 and Zinchenko 1985), supported by information and communication technology. Specialist spaces namely: art, science and design and technology have begun to reflect this paradigm by challenging the norm as outlined by BB98 (building bulletin 98). Examples include open plan 'art lofts' which are zoned to support a variety of activity rather than divided into a number of rooms and large open plan workshops which bring together all forms of resistant materials in one large space.

However, the approach can be taken further and deeper by emphasising the principles of social constructivism through every element of a scheme. Spaces can be developed which convey co-learning and the co-construction of knowledge. From an architectural perspective this

means thinking of the whole campus as a learning space rather than emphasising classrooms (Fielding Nare, 2007; Van Note Chism, 2006). Within any learning space it means avoiding the message that the room has a front or a 'privileged' space. Outside the classroom, it means providing ubiquitous places for discussion and study (Fielding Nare, 2007; Van Note Chism, 2006). It means that the flow of spaces – from library to faculty or administration to classroom and the corridors and outdoor passageways in between – must be rethought in terms of learning (Fielding Nare, 2007; Van Note Chism, 2006). Spaces should centre on learning not experts. However, it is important to acknowledge that space should be understood as including internal and external, formal and informal spaces because as Van Note Chism (2006:17) explains every space is potentially a learning space.

Learning takes place everywhere on a college campus, in fact learning arguably happens everywhere – on city sidewalks, in airplanes, in restaurants, in bookstores and on playgrounds. Human beings wherever they are have the capacity to learn through their experiences and reflections.

Despite this there is a lack of critical spatial and visual literacy (New London Group, 1996; Burgin, 1996) of occupants within learning environments, and in the community at large (Thorn, 1999), which has led to little opportunity to challenge spatial practice in educational design.

### **Pedagogy and space in design and technology, science and art**

When considering the concept of pedagogy in relation to specialist subjects it is important to understand the complexity of the subject in question. For the purpose

of this paper, I will focus on Design and Technology in this section and use it to exemplify my point as I de-construct the requirements of the current national curriculum in the United Kingdom. However, it is acknowledged that both science and art are equally complex and combined with design and technology as the specialist subjects in this context it illustrates that there is a great deal to take into consideration.

The Secondary Curriculum (DCSF, 2007), offers an important statement for Design and Technology. Showcasing as it does what design and technology is deemed to contribute to the 21st century curriculum, it is interesting to note the emphasis on both practical and technological skills, as well as the need to utilise creative thinking to design and make products and systems to meet human needs. However, in order to

fulfil the requirements of the national curriculum students need to utilise the key concepts of designing and making, cultural understanding, creativity and critical evaluation. This is undertaken whilst engaging in a range of key processes such as generating, developing, modelling and evaluating ideas in a range of ways using appropriate strategies. Students utilise these concepts and processes in resistant materials, systems and control and either food or textiles. This is captured in the diagram below (figure. 1), which is an overview of design and technology in the secondary curriculum.

Taking all of this into account it is clear that the design and technology facilities of the future will need to be very flexible, containing a range of different types of space, if they are to meet the needs of the 21st century curriculum and beyond.

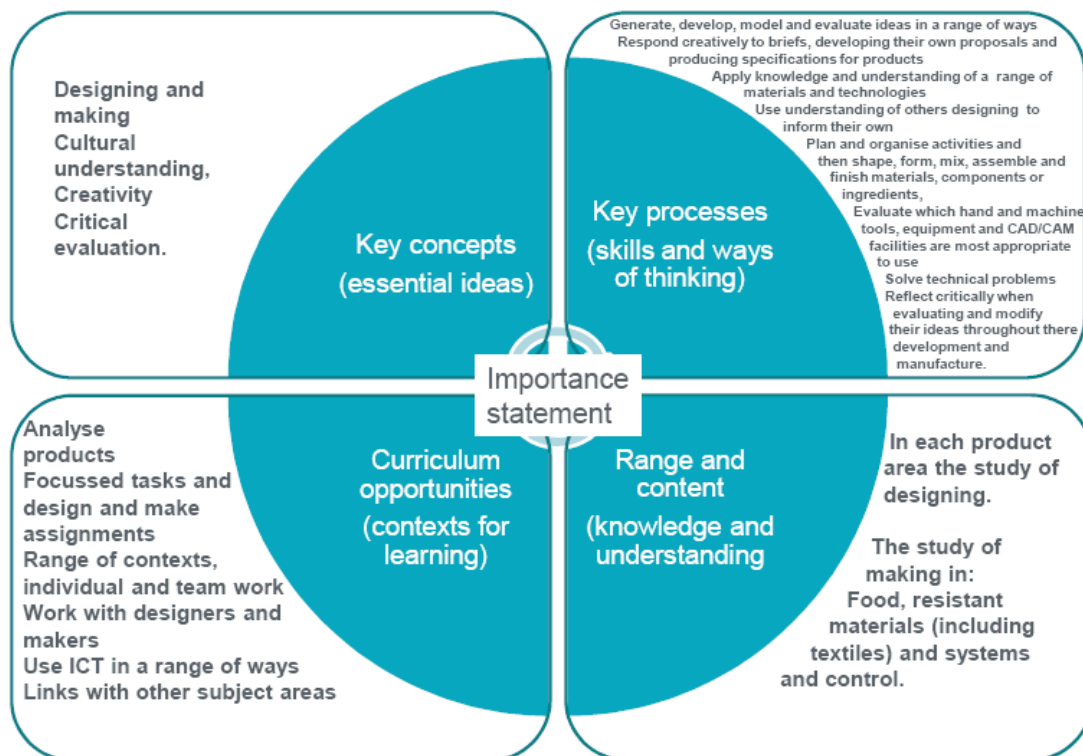


Figure 1. An overview of design and technology in the secondary curriculum

However, too little thought has been given to the provision of space in design and technology and the BB98 (building bulletin) list of 2 resistant materials workshops, resistant materials preparation, 1 food room, food preparation, 1 systems and control, 1 textiles and storage has often been followed regardless of whether it meets the needs of the curriculum. Key omissions relate to the fact that designing is an important part of design and technology and yet there is no provision for a designerly space and CAD/CAM is on every syllabus and yet once again no specific provision is made. This mismatch between pedagogy and space offers opportunities in this context to analyse the proposed provision in depth and to challenge the prevailing typology.

**Methodology**

In order to study how the metaphor ‘blurring the boundaries’ informed the architectural design of specialist learning spaces in this context a ‘case study approach bounded by time and focus group’ (Cresswell, 1998) was conducted.

The research was undertaken between April and October 2010 and ran in parallel with the design development of the Academy. During the design development a multi-disciplinary team consisting of architects, educationalists, landscape architects, engineers and construction workers took part in an iterative design process which included consultation with a broad range of stakeholders including, students, teachers and planners in order to ensure that the solution developed met everyone’s needs.

**The educational context and sample**

The site of the case study was an Academy in Kent specialising in Science and Engineering which aspires over time to have 1150 students on role with 250 in the sixth form. This Academy was chosen because the approach to the development of space within the specialist learning areas of design and technology, science and art presented a challenge to the norm by focussing heavily on the needs of the 21st century learner.

Client Team	Design Development Team
Academy representatives	An educationalist
Client architect who developed the reference scheme	A team of architects
The sponsor	A pre-construction bid team
The project manager	A landscape architect
Local authority representatives	An M&E engineer
	A structural engineer

Table 1. An overview of the client and design development teams

During the process additional engagements were held with the following people:

- the student council;
- three design and technology teachers, two science teachers, one art teacher, one science technician and one design and technology technician.

It should be noted that the consultations listed above took place during the invitation to tender (ITT) stage of the programme and that once the team were accepted as preferred bidder a much larger consultation process took place. Any consultation is limited during the ITT stage as there are two bid teams working on the project at this point and sight of two schemes in the local area can become confusing.

**Data gathering**

In order to create a rich picture of the context, a range of data collection methods were used in order to enable the triangulation of data. These included scrutiny of the education brief, notes from client engagement meetings, concept sketches, sketch plans, detailed plans, concept sketches and detailed landscape plans.

Data were collected throughout the design development process and analysed against a range of categories drawn from the literature, supplemented by categories derived from the data.

The data gathering techniques are summarised in Table 2.

	Education brief	Notes from client engagement meetings	Concept sketches, sketch plans, detailed plans and physical architectural models	Concept sketches and detailed landscape plans
<b>Data set A</b> Collected prior to the design development process beginning				
<b>Data set B</b> Collected during client engagement meetings				
<b>Data set C</b> Produced for client engagement meetings				
<b>Data set D</b> Produced for client engagement meetings				

Table 2. Data gathering techniques



Data presentation, analysis and discussion  
 One research question drove this study:  
 How does the metaphor 'blurring the boundaries' inform the architectural design of specialist learning spaces in this context?

In order to answer the question items from data sets A, B, C & D collected throughout the design development process will be presented, analysed and discussed.

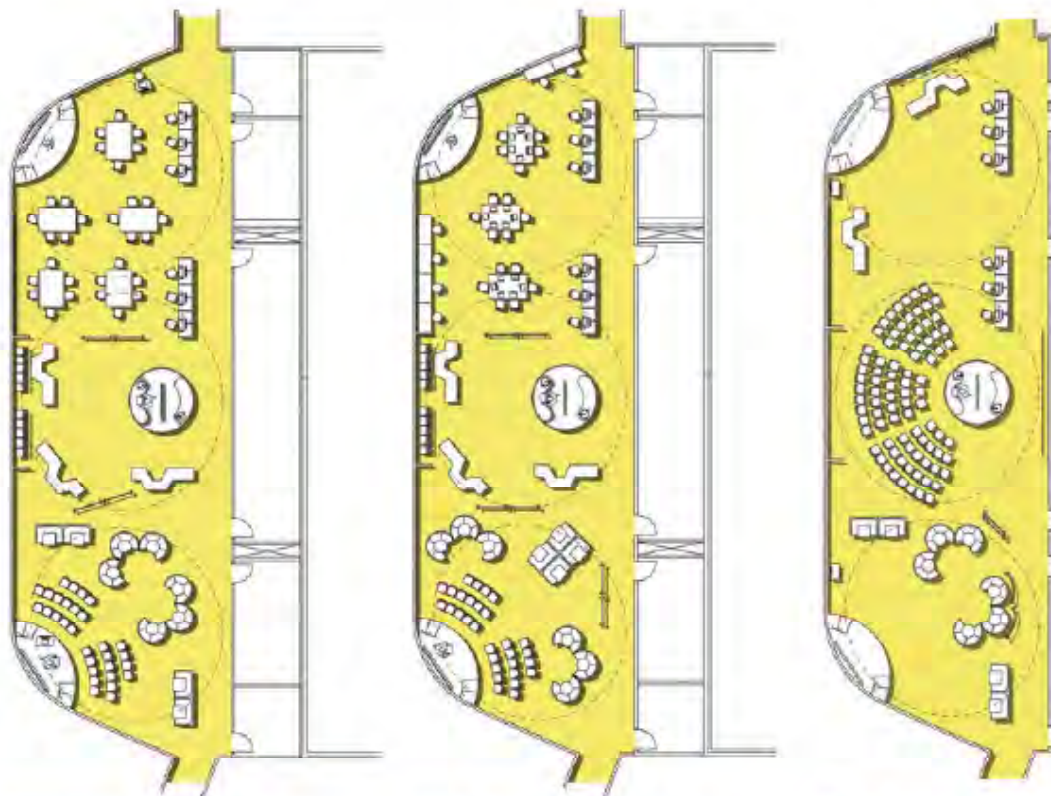
**Presentation and analysis of data**  
***Deconstructing the educational brief***

In the case of the specialist learning spaces in this scheme an integrated approach was developed between the architect and educationalist in order to interrogate the data. A number of questions and areas for exploration were identified and reviewed in detail at the first client engagement meeting. Table 3 below illustrates the areas of interest (listed in the left hand column), questions designed to interrogate the brief further, design implications and the Principal's response and additional notes. In this table it is clear

Specialist Zone	Questions	Design Implications	Notes
	Exploration of the adjacency diagrams – blurring of boundaries. Distribution over three floors. Vision for central space. Display interface with entrance. Exploration of internal/external connectivity.		The vision is the Guggenheim museum where ramps offer internal connectivity.  Must create a professional learning environment. (FFE team need to help test this)
Science	What do you mean by high spec labs given that they are the smaller spaces? For how many?  What is a semi-specced lab?  What do you mean by a demonstration space?	High spec labs are on schedule at 50m <sup>2</sup> . This will need to be tested because even with a class standing they are likely to need larger spaces. FFE consultants to test.  This is likely to be the same as a Faraday studio but needs testing  This is what they are likely to mean. (see <b>Science Demonstration space Image</b> )	All of the elements within the specialist areas will be important and should be showcased.  High spec labs are seen as spaces for long standing experiments Semi specced labs are for more general experiments  The image shown was viewed to illustrate a write up space rather than a demonstration space.  A demonstration space is as per Royal Society Christmas lecture space. Very inspirational, suitable for external speakers etc

<p>Engineering</p>	<p>What is your vision for engineering? High tech, low tech or a mix? At present on the SOA there are two RM workshops but no specific engineering ones. Will these both be for engineering?</p>		<p>External learning space associated with the specialisms is important and if direct connection is not possible a trail would be fine.</p> <p>The specialist zone will not be a house base and therefore does not need to have lockers</p> <p>High tech – FFE to test this</p> <p>RM is engineering</p> <p>In order to explore the vision for the specialist areas we have agreed to run a specialism workshop possibly on the week of the 24<sup>th</sup> May from 3.30 – 6.30. Proposal to be forwarded to the project manager.</p> <p>It was also agreed that a half day student engagement meeting would be undertaken during the same week but separate from the specialist engagement.</p>
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Table 3. (continued)



Furniture can be arranged differently in the science demonstration area. Here the north end is used for group work around tables – with some using laptops – while the south section is used for small group and independent working. Mobile whiteboards add flexibility.

Here the demonstration area is set up for using laptops in the north section and small group discussions in the south. The central section may be used for individual work by students from either north or south sections.

Here the demonstration area is used as a single space, set up so that half a year can see a presentation, perhaps from a visiting scientist. The chairs shown are stored along the left hand wall when not in use.

that the general approach to the organisation of learning is well defined in the educational brief. However, the detail such as how the high spec laboratories actually function had yet to be clarified.

Detailed analysis of this kind was carried out in relation to a number of key issues including ethos and values, teaching and learning, vocational education, support for learning, ICT and internal and external connectivity. This enabled the educationalist to de-construct the education brief through questioning and verbal modelling and re-construct it using written modelling in a way which represents a set of guiding principles for use by the design team. For example through discussions relating to the specialist learning zone it became clear that the space needed to be designed in order to 'blur the boundaries' across the subjects allowing students and staff to see the links and work towards a 'fusion' of learning experiences. It also became clear that the client team were keen to explore

the links between pedagogy and space and to re-define existing concepts for specialist learning in order to meet current and future curriculum needs. This led to them requesting a range of spaces in this area including high spec laboratories, semi-spec laboratories, engineering workshops, a pneumatics, electronics and control technology studio (PECT), a food technology room, a catering room, demonstration theatre, write-up spaces and easy access to a wide range of external learning opportunities designed to support the delivery of the curriculum.

**Educational concept sketches**

Having interrogated the Educational Brief for the specialist learning zone, it was possible using graphical modelling to produce an educational concept sketch which articulated the core components of this learning zone as shown in figure 2 below as a development of the adjacencies diagram provided as part of the outline business case documentation

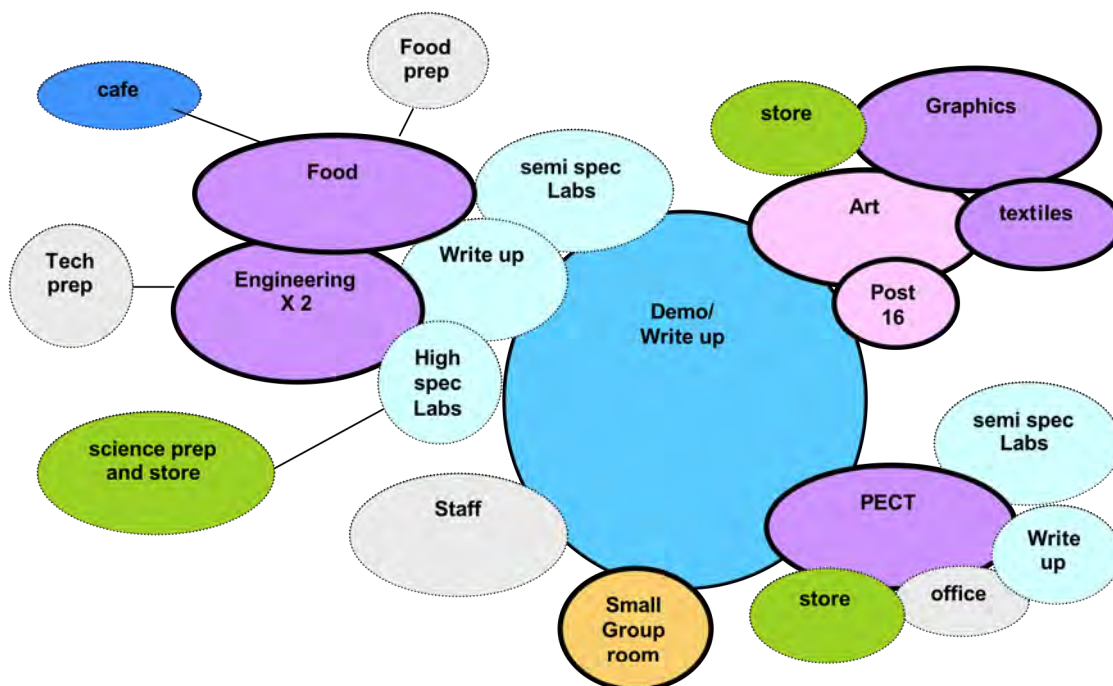


Figure 2. Educational concept sketch for the specialist learning zone



visual modelling techniques and then as scale plans which bring together both visual and numerical modelling in order to show increasing levels of detail. Below in

figures 4-5 is a selection of the plans tabled during the process showing the design moving from concept to detailed design.

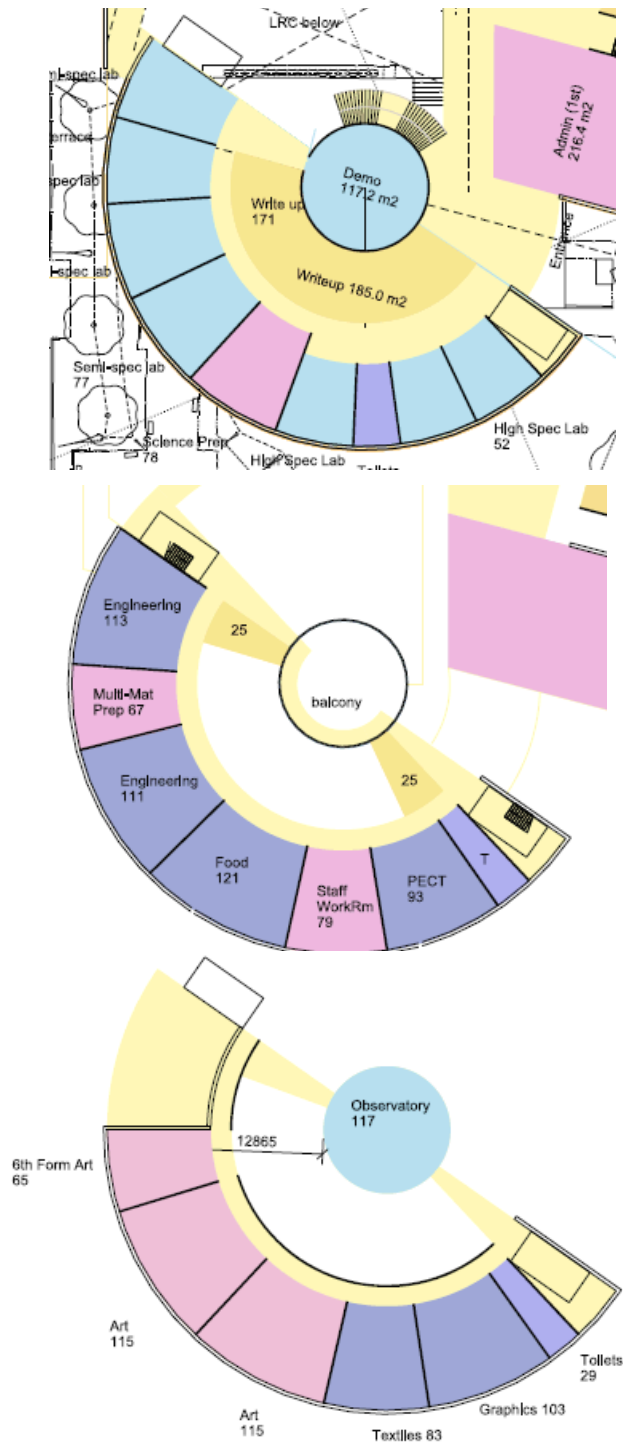


Figure 4. Early concept sketch



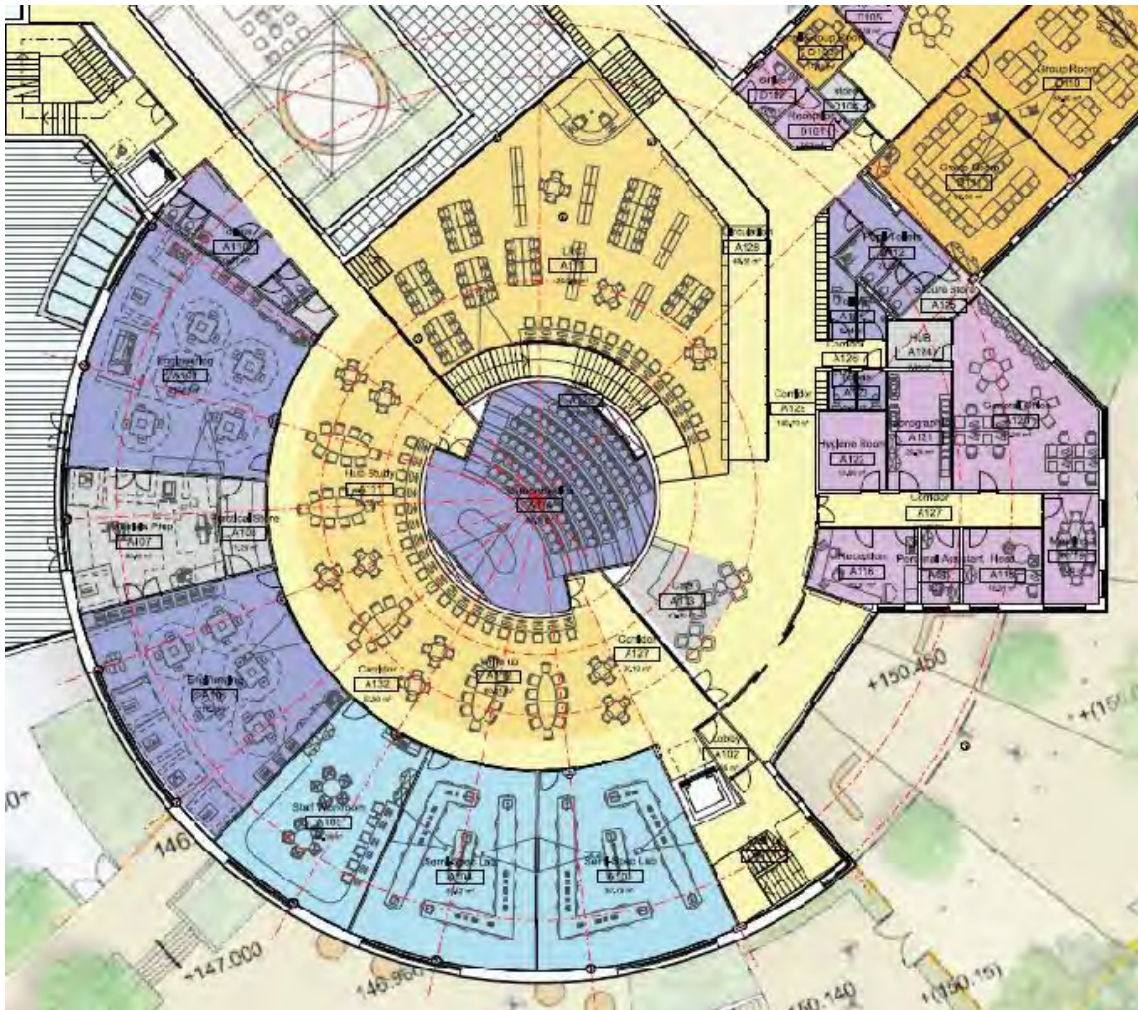


Figure 5. Detailed plans illustrating the 'blurring of boundaries' across the floors (part 2)

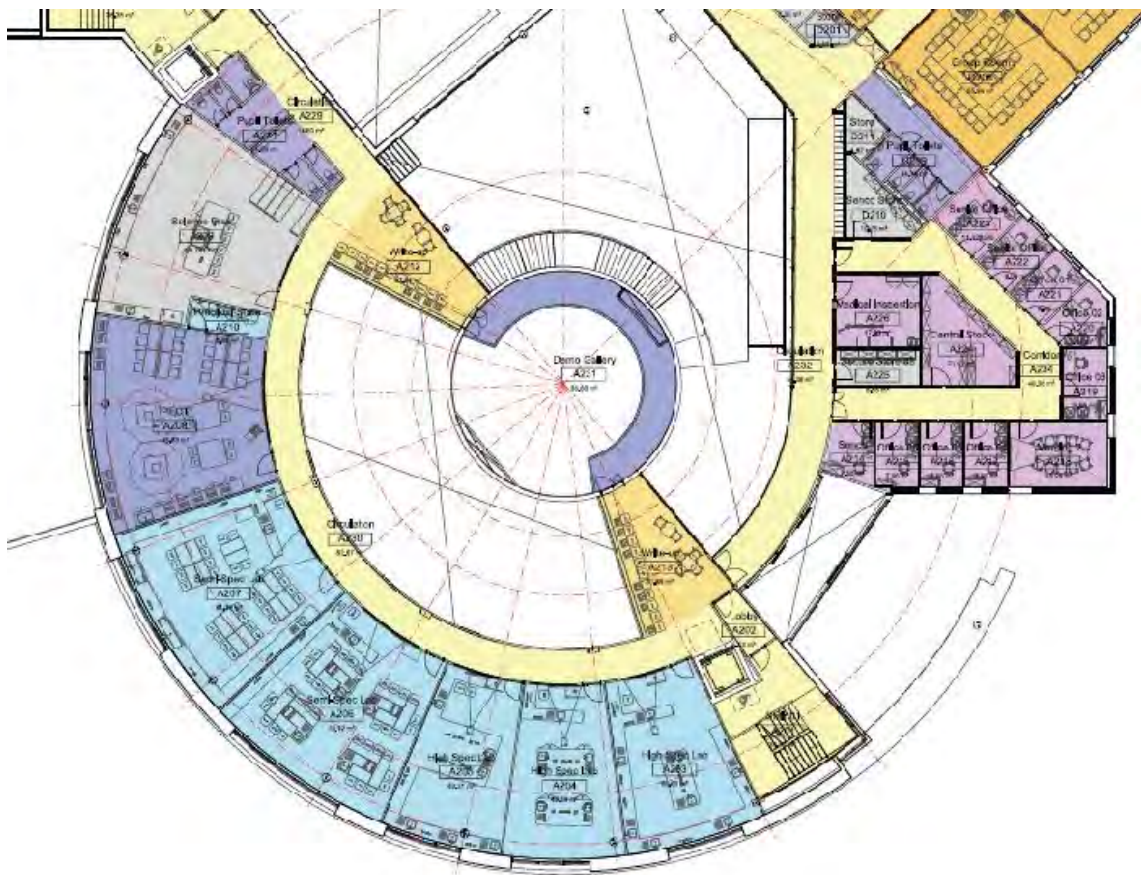


Figure 5. Detailed plans illustrating the 'blurring of boundaries' across the floors (part 3)



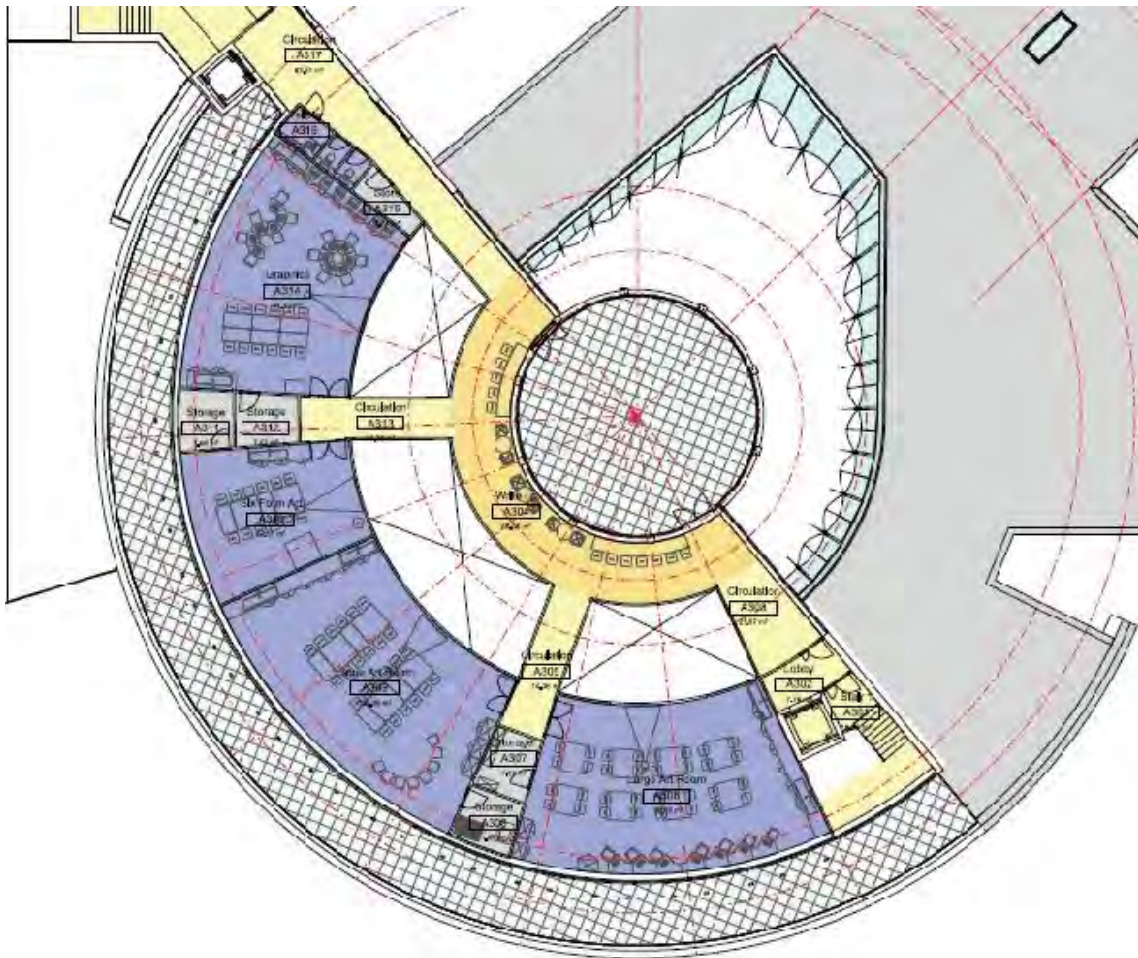


Figure 5. Detailed plans illustrating the 'blurring of boundaries' across the floors (part 4)

This approach proved to be a useful way to develop the detail of the design as the weeks progressed, with the big picture moving to fine detail and gaining and acting upon feedback from the client engagement meetings throughout the process. In this way visual modelling (the plan) can be used to support verbal modelling (explanations of the plan), whilst numerical modelling is employed to ensure that the plan is a scaled representation of reality which can over time be communicated through material modelling in order to show the design development in three dimensional format.

It should be noted however, that in this context the plans were mounted on foam board and stacked as a three dimensional model in order to offer a transition from two dimensional visual modelling to three dimensional material modelling. This approach was particularly successful in this context

Throughout the design development the input of the multi-disciplinary team was vital to success. For example the educationalist reviewed the plans on a regular basis noting as shown below where key elements of the vision had been prevented by a design decision that had been taken.



Figure 6. Modelling tool used during engagement sessions



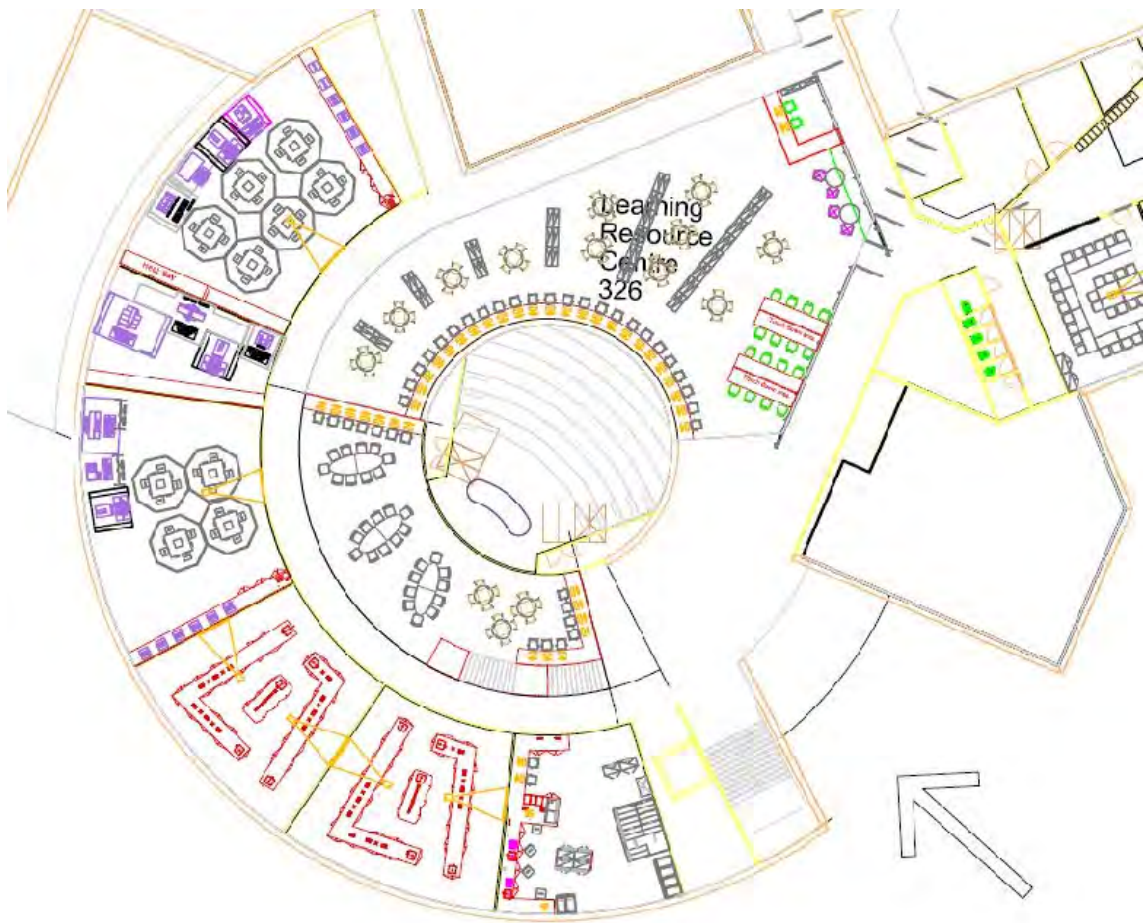


Figure 8. A loaded floor plan used to explore the approach to design and technology and science

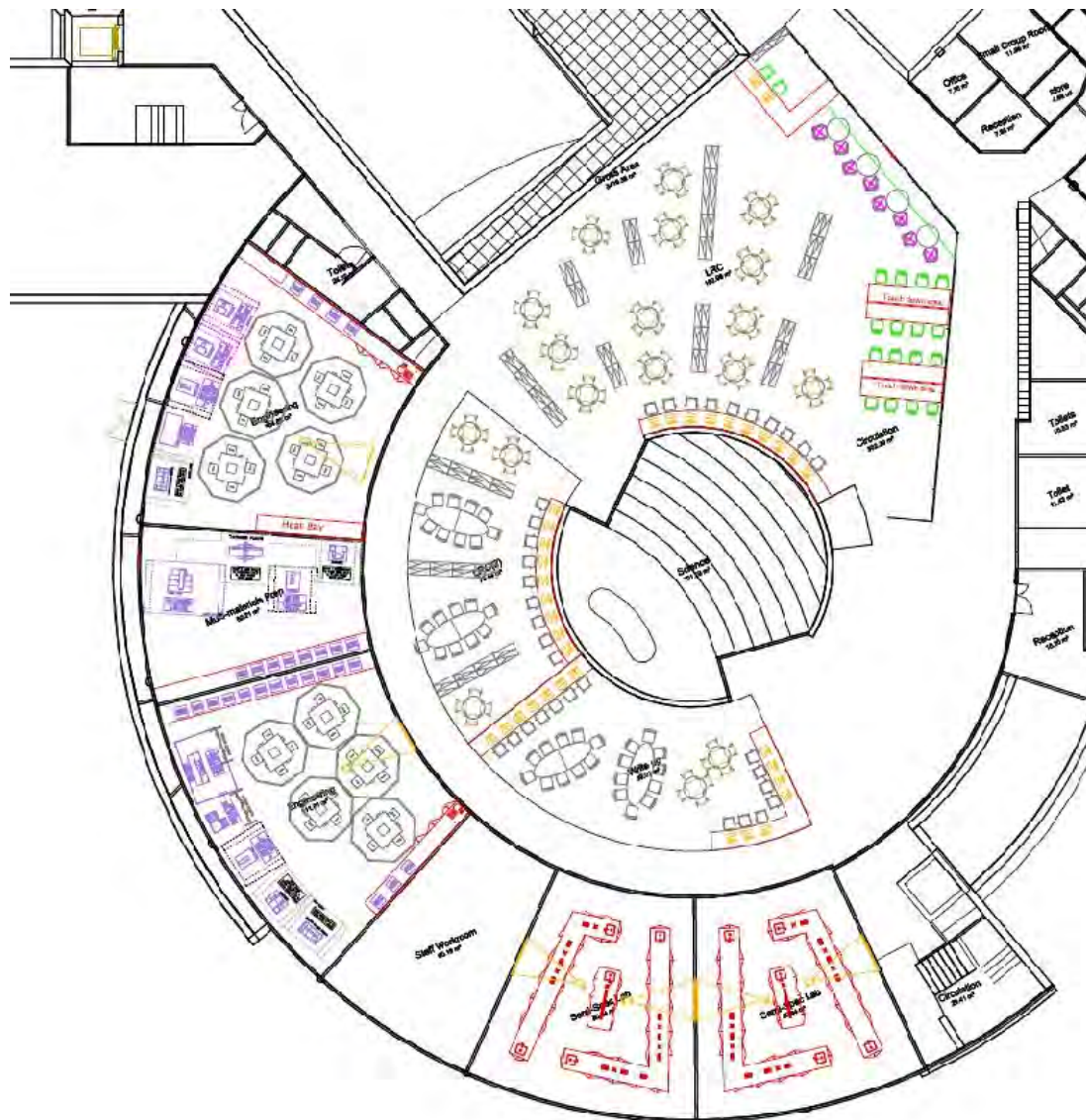


Figure 9. A developed loaded floor plan which takes account of comments from the design and client teams

It should also be noted that during the 12-14 week design development process, there are six client engagement meetings which are used to present developments to the client and to gain feedback. During each of these detailed notes were taken which were then used to inform further design development. Examples of abstracts from the meeting notes are shown below:

this will not be used as a house during pastoral time. Connectivity to external learning is important.

Spaces to be professional learning spaces e.g. graphics could be a design studio etc. Engineering is to be high tech

In these statements the Principal is giving clear guidance in relation to the nature of the spaces to be created.

Demo space needs to be a defined space. Think Royal Society. Specialist spaces to be those you go into whereas the write up spaces are open and fluid but of a range of sizes

In this example it is possible to see how the Principal references precedent such as the Royal Society lecture theatre to inform our thinking.

Write ups as shown are too fluid and too open. Specialist spaces are too fragmented. They do not merge or fuse enough. Studios and labs need to be adjacent to write up but write up is separate.

And here it was clear that the vision had yet to be embodied in the design and that the feedback gave the design team solid guidance as to the design decisions which needed to be made in order to meet the brief.

Throughout the design development there were numerous examples of this kind of interaction which enabled the design team to co-construct developments with the client team.

### **Flexibility**

It was also important to ensure that any spaces were designed with flexibility in mind. Taking Torin's (2002) flexible space and building pedagogy properties namely: fluidity, versatility, convertibility, scalability and modifiability it is possible to analyse the proposed spaces within the specialist learning zone in order to identify the nature of their flexibility.






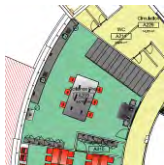
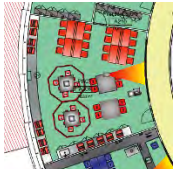
Types of space	Illustration of space typology	Flexibility properties	Comments
Engineering workshops		Convertibility, scale ability	Although these will include fixed machinery the construction techniques proposed mean that the partitions can be easily moved when required, thus allowing the creation of a larger or smaller space.
Multi-materials prep room		Convertibility, scale ability	Although these will include fixed machinery the construction techniques proposed mean that the partitions can be easily moved when required, thus allowing the creation of a larger or smaller space.
storage		Convertibility	The construction techniques proposed mean that the partitions can be easily moved when required, thus allowing the creation of a larger or smaller space.
High spec laboratories		Convertibility, scale ability	Although these will include fixed furniture the construction techniques proposed mean that the partitions can be easily moved when required, thus creating a larger or smaller space.
Semi spec laboratories		Convertibility, scale ability	Although these will include fixed furniture the construction techniques proposed mean that the partitions can be easily moved when required, thus creating a larger or smaller space.
Science prep room		Convertibility, scale ability	The construction techniques proposed mean that the partitions can be easily moved when required, thus allowing the creation of a larger or smaller space.
PECT studio		Convertibility, scale ability	The construction techniques proposed mean that the partitions can be easily moved when required, thus allowing the creation of a larger or smaller space.

Table 4. Flexible space and building pedagogy properties


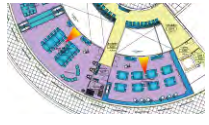

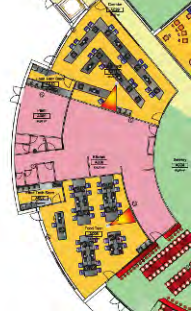

Graphics studio		Convertibility, scale ability	The construction techniques proposed mean that the partitions can be easily moved when required, thus allowing the creation of a larger or smaller space. It would also be possible to turn the whole top floor into an open plan art barn by removing the partitions.
Art studios		Convertibility, modifiability, scale ability	The construction techniques proposed mean that the partitions can be easily moved when required, thus allowing the creation of a larger or smaller space. It would also be possible to turn the whole top floor into an open plan art barn by removing the partitions. Re-configurable furniture could then be used to zone and re-zone the space in order to offer a wide range of learning opportunities.
Post 16 art studio		Convertibility, modifiability, scale ability	The construction techniques proposed mean that the partitions can be easily moved when required, thus allowing the creation of a larger or smaller space. It would also be possible to turn the whole top floor into an open plan art barn by removing the partitions. Re-configurable furniture could then be used to zone and re-zone the space in order to offer a wide range of learning opportunities.
Food Rooms		Convertibility	The construction techniques proposed mean that the partitions can be easily moved when required, thus allowing the creation of a larger or smaller space.
Food preparation space		Convertibility	The construction techniques proposed mean that the partitions can be easily moved when required, thus allowing the creation of a larger or smaller space.

Table 4. (continued)




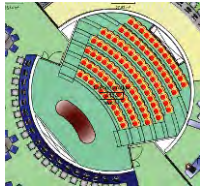
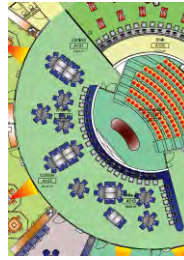
Staff work area		Convertibility, scale ability	The construction techniques proposed mean that the partitions can be easily moved when required, thus allowing the creation of a larger or smaller space.
Shared demonstration space			As a fixed element which offers structural integrity the demonstration space is not a flexible space. However, it has been designed to be used by any of the specialism team.
Write-up spaces		Modifiability, fluidity, versatility.	The provision of re-configurable furniture in the write-up spaces ensures that they can be modified in order to offer a range of learning opportunities. Fluidity in this context manifests itself in open spaces which support the flow of individuals, sight, sound and air. Versatility is achieved because the spaces support multi-use.

Table 4. (continued)

As can be seen from this analysis all but one of the spaces has a range of flexible attributes. Where this is not the case i.e. the demonstration theatre this is because the space has been designed to perform a structural function

**The legibility of plans**

As part of the design development it was important to present ideas in as many formats as possible in order to ensure that all of the client side team could understand the nature of the spaces that were being created. To this end a fly through was created and the stills used to explain key elements. This turned out to be a very effective form of visual modelling which brought the design to life.



Figure 10. Birds eye view



Figure 11 – Entrance plaza



Figure 12. Specialist learning zone

### **Landscape plans**

'Blurring the boundaries' was not only used to inspire an approach to the specialist learning spaces but also to inspire a relationship between internal and external learning opportunities. This was achieved by ensuring that the landscape designer attended most of the client engagement meetings and that the proposals for the use of space both internally and externally were presented together in order to ensure a holistic understanding. The plan opposite illustrates how important this approach was and how it supported the realisation of the vision.



Figure 13. Landscape master plan

In the case of the specialist learning zone as shown below, the landscape offered opportunities to undertake project activities relating to art, design and technology and

science in the fusion garden. To grow vegetables in the allotments and to serve buffets and BBQs as part of catering courses on the external dining terrace.



Figure 14.  
From top to bottom, fusion terrace, allotments and science pond and external dining

**Discussion**

In answering the research question: How does the metaphor 'blurring the boundaries' inform the architectural design of specialist learning spaces in this context? It has been important to focus on each of the activities outlined in the key activities pentagon as described previously (Trell, 2010) namely: (a) Deconstructing the Educational Brief, (b) Educational Concept Sketches, (c) Architectural Concept Sketches, (d) Architectural Plans and (e) Landscape Plans. In doing so it has been possible to understand how the metaphor 'blurring the boundaries' has informed the architectural design of

specialist learning spaces in this context. It has also been possible to illustrate some of the relationships between modelling and designing, in particular the translation from one form of modelling to another in order to facilitate design development.

Through the analysis of the specialism section of the education brief it became clear that the Principal liked to illustrate her point by referencing precedent. This allowed the architects to develop an inspiration board by translating verbal modelling into visual modelling which could be used to inform design development.

**The Influences**

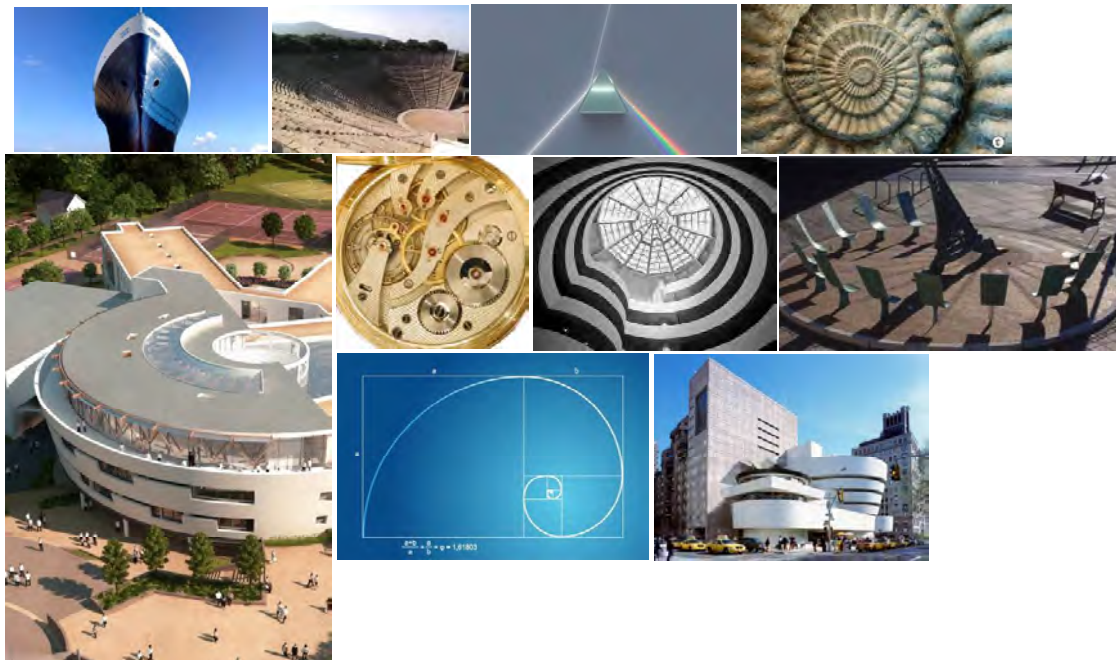


Figure 15. Inspiration for the project

When analysing this it is clear that even at this point the inspiration itself explored the 'blurring of boundaries' from the Fibonacci sweeps merging of mathematics and nature as exhibited in the sunflower below to the mix of engineering and physics evident in the sun dial. The sunflower bloom has spirals formed by the ovules (soon to be seeds). If you print this image and count the spirals, you'll find there are 55 that sweep to the left as they spiral outward, and 34 that sweep to the right. These are the 10th and 9th Fibonacci numbers, a Fibonacci pair. Different flower species have different numbers of spirals, but always, barring damage during growth, they form a Fibonacci pair.

Another point of interest is the spiral within the Guggenheim museum which 'blurs the boundaries' across the floor plates, thus

fusing the experience as you move around the museum.

### **Blurring the boundaries through the positioning of key spaces**

During the design development the metaphor 'blurring the boundaries' was used as the inspiration leading to the placement of a mix of specialist spaces across levels, that is food technology at lower ground floor, engineering and science at ground floor, science and electronics at first floor and art and graphics at second floor. This approach was taken in order to offer a physical manifestation to the term 'blurring the boundaries' which has the capacity to encourage students and teachers to explore the links across subjects.



Figure 16. Blurring the boundaries between mathematics and nature

### **Blurring the boundaries through the nature and placement of the spaces**

In this particular context the team were challenged to provide professional learning environments which have the capacity to emulate the world of work supported by write-up spaces. This meant thinking of high spec laboratories as spaces for practical experimentation. Art and design and technology spaces as design studios and the engineering workshops as somewhere to make high quality products using the latest computer aided design and manufacturing facilities. All supported by large areas where write-up and designerly activity could take place. This approach was taken in order to offer appropriate spaces for write-up activity in areas which would begin to incubate collaborative practice.

Blurring the boundaries through the provision of shared multi-functional spaces Having been asked to blur the boundaries another important move was to provide a demonstration theatre which could be used by the art, design and technology and science staff for guest speakers, project launches and large demonstrations. This space is centrally positioned in order to promote a feeling of shared ownership and as such encourage shared use. This was done in order to provide a professional learning environment, in which young people can hone presentation skills, listen to industrial lectures and enjoy demonstrations whilst once again beginning to see the links across the specialist subjects.

### **Blurring the boundaries by providing shared staff work bases**

Having set the precedent of shared floor plates it was important to provide a shared staff work base for use by all of the specialist teachers. This space has been

provided in order to encourage staff to share practice across subjects both formally and informally in recognition of the fact that some of the best ideas are conceived in collaboration with colleagues.

### **Blurring the boundaries by creating a building that can teach**

Most importantly when considering 'blurring the boundaries' it was vital to emulate this through our own work by providing a building that can teach key concepts in this area of the curriculum. Examples include the use of the fibonacci sweep as a core feature of the building design, which if shared with students can support curriculum delivery in science, art and maths. The shape and form of the building, the geometry of which can inform maths and the interest of which can inspire students in art and design and technology. This approach was adopted to make the point that the boundaries of subjects are not only 'blurred' but often do not exist in industry.

Blurring the boundaries as a metaphor for current educational change

In adopting the approach explored in this paper, the design team have developed a scheme which will enable its users 'to adopt changes in approaches to learning, teaching practices, relationships and school organisation' (Rudd, 2008: 6). Taken together this will enable the design to support transformation by moving from 'a 'learned institution' to a 'learning community' where what is learnt, by whom, when, who, with and how becomes more fluid, emergent and evolves based on need and opportunity' (Rudd, 2008: 6).



### **The place of modelling in design development**

Given the complexity of the ideas embedded in this scheme it was important to utilise a range of modelling techniques throughout the process in order to communicate complex ideas. For the purposes of this paper Kimbell and Stables (2007) definition of modelling is used which is as follows:

- visual modelling where ideas are progressed through sketching;
- written modelling where ideas are progressed through annotation;
- verbal modelling where ideas are progressed through discussion;
- numerical modelling where ideas are progressed through the use of numerical calculations;
- material modelling where ideas are progressed through the development of three dimensional representations.

Design development in this context began with the de-construction of the educational brief using written modelling (annotation) which was used to challenge assumptions with the client through verbal modelling (discussion). Once the fundamentals were understood, visual modelling (sketching) was used to produce concept sketches and these were reviewed in detail using verbal modelling (discussion). Having agreed developments, ideas were progressed into detailed plans using a combination of numerical (scaled plans) and visual modelling (plans). Where necessary material (3D representations), and verbal modelling (discussion) were used to test ideas with the client. Once the ideas had been refined high quality visual

modelling through the development of fly through images were used to test the detail of the design.

### **Conclusion**

In summary findings illustrate that an integrated approach encapsulating educational, architectural, information communication technology, mechanical and electrical and furniture, fittings and equipment inputs into the design development of the specialist learning spaces is a key feature in the journey from vision, through interpretation to reality in this context. This approach is so powerful when considering how the metaphor 'blurring the boundaries' informs the architectural design of specialist learning spaces in this context because it represents how art, science, engineering and technology function in industry with strong overlaps across the fields of expertise which can be used to drive value from projects.

The paper also illustrates the complexity of the design process in this context and the need for a wide use of modelling techniques in order to support the co-construction of the final design.

### **Further research**

With the Building Schools for the Future Programme now at an end but the design development of academies on-going, it will be important to continue to track school design from Education Brief to the realisation of space, and over time through longitudinal studies, the effectiveness of the spaces in action and their impact on learning outcomes. This journey began with a study of multi-disciplinary interaction in learning led design (Trebell, 2010) and continues here. However, there is much left to do and it is very important that the educationalists perspective is added to that of the many architects publishing

papers on school design. This will help ensure that educational establishments are studied in terms of the relationship between pedagogy and space (Fisher, 2002, 2005, 2007), as well as architectural

functionality. Through this approach it is hoped that a coherent and well evidenced approach to Learning Led Design will emerge.

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## Continuity and progression in graphicacy

*Xenia Danos and Eddie Norman*

### Abstract

*Graphicacy is defined, and both its importance and relative neglect as a research area in relation to literacy and numeracy are discussed. The outcomes of a literature review are presented and the developmental stages of mark-making described, based primarily on research by Gaitskell, Lowenfeld and Kellogg. Supporting and contradictory opinions from a range of authors are brought together and differences noted. Strategies for addressing the emerging research agenda are then discussed, and particularly for the development of descriptors of continuity and progression in graphicacy. A taxonomy for the analysis of graphicacy within curricula is presented, and potential research methodologies for exploring graphicacy within different areas of the taxonomy are then reviewed. Three of these areas: analysis of tasks, co-research and the validation of research outcomes through a Delphi study are discussed in detail.*

### Introduction

Visual communication is the development and conveyance of ideas and information in forms that can be read or looked upon. The skill required for dealing with visual communication is 'Graphicacy', which is defined as the ability to communicate

using still visual images, such as graphs, maps, drawings etc. The power of images has great possibilities and potentials. It can break through the barriers of language and academic status. It can change one's perceptions and decisions. It can be used as a tool for learning and for recording thinking. In our schools' curricula, we find literacy, numeracy and articulacy being the main focus areas across the subjects, placing no substantial efforts towards graphicacy. However, in all subjects, lessons are primarily taught with the use of verbal and visual communication. Despite this, the teaching of understanding and working with different types of images takes up little space in the curriculum.

Graphicacy was first explored in the 1960s by Balchin (1966) and subsequent research was completed in a number of countries. In the 1970s Fry developed a taxonomy of graphs, which was effective at that time but had not been up-dated. The need for such an update is illustrated in

Past research has highlighted the importance of visual communication in a variety of subjects, including the sciences, mathematics, geography and art and design. It also revealed research conducted on gender differences, map reading, cartography, graph reading and other areas relating to graphicacy.

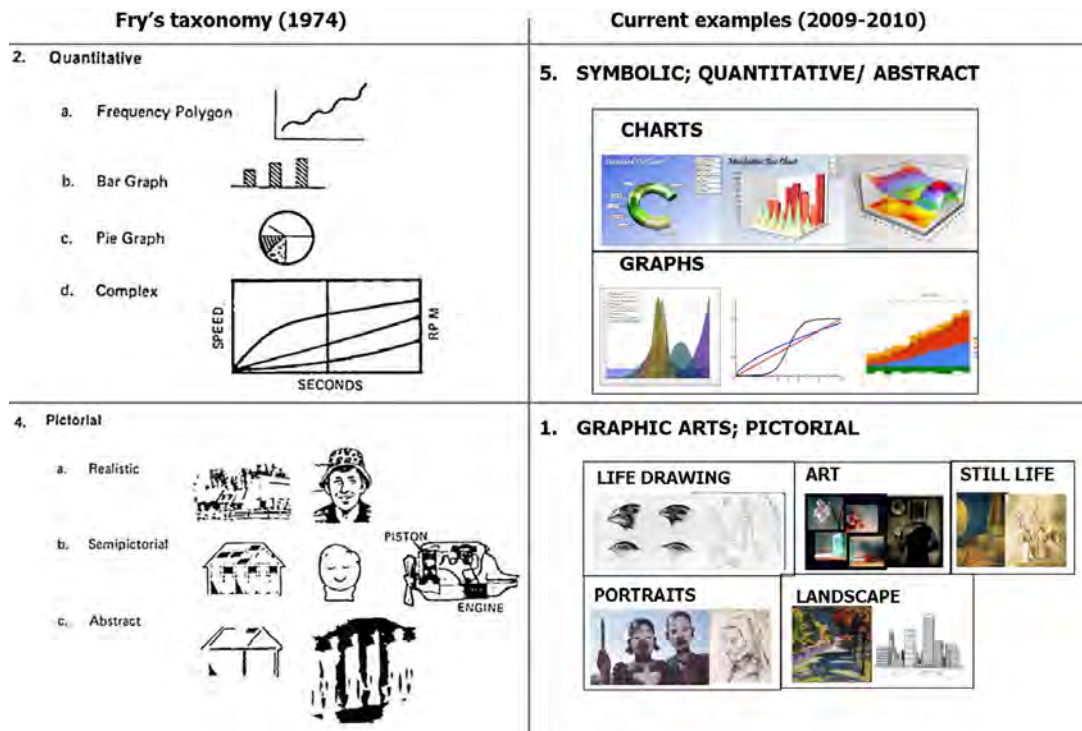


Figure 1 Images from Fry's taxonomy (1974) Vs recent examples

A detailed literature review was conducted and its outcomes are summarised in the first section of this paper. However, it was evident that there had been little advance on the position described below by Kellogg in 1970.

Teachers are confused by art educators who advise them to approve all child work in order to avoid discouraging further effort, but not to praise work unless it is up to the standard for the age level. Yet nowhere are age level standards defined in a way that is both objective and usable in an ordinary classroom. Thus each teacher's personal taste actually becomes the final measure of age-level achievement

(Kellogg 1970: 152)

Consequently the key focus of this paper is towards making progress on this major research agenda. In order to support practice in this area, it is necessary to work towards answering research questions, such as the following.

- Can a taxonomy of graphicacy be developed that can act as a framework for research in this area?
- How can continuity and progression be defined in any area of such a taxonomy for graphicacy?
- Which research methods can give usable results?
- Can a Delphi study help to validate the outcomes?
- Can co-research support the data gathering?

The later sections of the paper describe progress that has been made towards addressing these research questions.

## Literature review

This literature review was conducted to get a general understanding of previous work concerning the development of children's art, drawing and mark-making (outgoing graphicacy skills) and to identify the main stages/levels of visual-spatial ability that children go through.

### Development of mark-making and drawing capability

The review revealed the limited amount of information which exists regarding human development and progression in drawing; more specifically, children's abilities to create images. Detailed work was conducted by Kellogg in the 1970s, which describes the stages children go through in drawing, from ages 1 ½ to 8 years old. For older children, other researchers have looked at development and progression in a more generic way, identifying stages covering longer periods of development (2 years and more).

The first stage is often referred to as 'scribblings' or 'random scribblings' and it is considered universally to be a child's first mark. Opinions on the skills required to create these scribbles vary. Gaitskell believes that when children first go through the manipulation stage, their mark making is done in an 'exploratory and random fashion and then to a controlled movement that leads to making art on purpose such as recognizable or nameable objects' (Gaitskell, 1958). Others believe that scribbles 'demonstrate awareness of pattern and increasing eye-hand coordination' instead of just being 'aimless or uncoordinated movements' (Lowenfeld & Brittain, 1987; Kellogg, 1970).

From around 2 years old, children might label or name the scribble before they draw it, and they might change the name

later if it reminds them of something different. Kellogg believes that naming the scribbles is the result of adult influence, whereas Lowenfeld believes it to be 'one of the important stages in human development (covering ages from 1 to 4 years old) as it indicates a change of thinking from a mere kinaesthetic to an imaginative' stage.

After the age of 3, children go into the 'Design' stage where they start producing 'Combines' (2 diagrams joined together in one drawing) and 'Aggregates' (3 or more diagrams joined together). These can appear simpler in construction than certain basic scribbles made at a younger age, but they are considered to be more advanced developmentally. They show the child's desire to draw lines in meaningful relationships. Gaitskell (1951) details 10 elements of design: balance, line, mass and space, light and shade, texture, colour, rhythms, movement, unity and centre of interest. At this stage children can include all but light and shade and texture in their drawings. According to Gaitskell, children stay at this stage for about a year, before they start producing drawings with pictorial qualities, which is a position supported by Kellogg. The first pictorial drawing children produce is of a sexless, ageless human figure, followed by flowers, animals, boats, houses and vehicles. Opinions on the 'armless human' vary amongst academics, ranging from it being due to aesthetic values to demonstrating a relationship to mental and psychological factors.

Gaitskell calls all the above stages the 'manipulation stage' which he believes covers ages 1 to 5 years old. Stage two, as defined by Gaitskell, is the 'symbolic stage', recognised by the use of symbols, starting at 3 and lasting until 7, or there

might never be clear progression beyond it. This stage is characterised by the type of drawings Kellogg names as 'pictorial work', where children use fixed symbolic representations for objects, i.e. the circle with short lines around the perimeter for a sun, stick men figures etc. (Gaitskell, 1951).

Gaitskell continues to describe children's developmental stages until the 'mature productive artist' stage. He believes that from as early as 9 years old, students enter the 'realism stage' where they begin to become more critical of their work or express a deep desire to get new knowledge to help them improve. Similarly, Hope (2008) believes that children start feeling dissatisfied with their drawing output as early as 7 years old. Gaitskell believes this is the right time for children to begin learning the basics of art such as direct observation from real life.

The final stage as defined by Gaitskell reflects the 'process used by mature productive artists' (Gaitskell, 1951). Inventiveness and deeper thought are applied in an effort to make specific statements either defined by themselves or others for creative art, advertising or design.

Figure 2 shows Kellogg's and Gaitskell's perspectives alongside that of Lowenfeld. Lowenfeld, Kellogg and Gaitskell all supported the belief that there is an observable order for the development of children's drawing abilities, which relate to age groups, where they adopt recognisable modes of artistic expressions. Kellogg has drawn her conclusions from work conducted over a period of 20 years, with a very large number of drawings having been analysed. Kellogg's studies have been primarily focused around children's drawing development between the ages of 1-8.

Kellogg's work has produced detailed phases with clear progression stages; perhaps the most detailed analysis of children's development in drawings between those ages. Gaitskell studied children's art for many years while working closely with school teachers and sought to give some guidelines to help in the teaching and evaluation of students' art. Four main stages were identified which were based on the type of images created by the child as described above.

Lowenfeld (1947) connected intellectual growth, psychosocial stages and children's drawings to generate six stages for the development of children's drawings. His appreciation of individual's work is largely characterised by interpretations of a psychological nature. He viewed children's art as documents that reveal child personality, instead of as just lines and forms, as was the case in Kellogg's work. He claimed that children's work is either 'visual' or 'haptic', reflecting the child's sense of touch and their muscular and kinaesthetic awareness. His terms describe characteristics that have more to do with matters of character.

### **Other perspectives on drawing and mark making**

The common thread of all of the above positions is that the graphicacy capability of children develops with age, although the viewpoints differ on the period of occurrence of each stage. Luquet (1927) supported the idea that children have an internal model from which they extract knowledge when drawing, which in many children appears to be very similar at similar ages. He also supported that artistic development never develops in one direction or in a constant order due to cultural and educational aspects. Another common view is that children experience some kind of regression phenomena in

regards to their artistic development, which is dependent on their cultural, social, mental and physical growth (Luquet 1927, Lowenfeld 1947).

Harris' (1971) research on children's basic scribble patterns supports the above idea. The 20 scribbles identified by Kellogg, which are described as a universal propensity in scribble patterns with the growth of children's motor skills, were used for this research. Harris found that tendencies differ depending on culture and society, and not incidentally, drawing experience. According to Harris, some native people (the South American Andes Indian, Bedouins from the Sinai Peninsula, and Kenyan children) tend to skip to drawing figures without the process of diverse scribble patterns. Balchin (1966) also believed that it is possible for children to 'skip' some of the initial stages (random scribbling, scribbling, simple diagrams etc.), if the child did not have the opportunity to create marks at the appropriate age and yet be able to create drawings fitting in the 'correct' stage for their age. However, Kellogg states that 'the opportunity to scribble freely has meaning for two critical operations of intelligence: reading and writing' (1970:262).

When finding similar aged children across different cultures creating different types of drawings, Golomb (1992) hypothesised that differences of representation in children's drawings may come from the difference of aesthetic to which children are accustomed.

Another controversial view exists around children's abilities concerning the use of style when drawing. Winner (1982) supported that children between the ages of 6 to 10 do not have the ability to express mood with colour or lines. He felt children at that age were oblivious to different ways

and styles of drawing and felt their drawings were accidentally created. Arnheim (1974) agreed with Winner's view and claimed that there was no certain evidence showing children using or having advanced intellectual concepts which are needed for abstract thinking of symmetry, proportion or rectangularity. Many authors such as Kellogg (1970), Schweizer (1999), Edwards (1993), Harris (1971), Gardner (1980), Silk & Thomas (1990) and Lowenfeld & Brittain (1987) disagree over this issue of style and emotional expression.

Freeman (1980) found that young children (below 8 years old) produced drawings that emphasised known facts about the object, whereas older children could draw objects as they were set in front of them correctly illustrating their viewpoint. Hope (2008:100) believed 'that children start from their own viewpoint and only later create powerful generalisations about the world since under the schema'. Piaget believed that young children are self-centric as they understand things from their point of view and do not have the ability to sympathise with an adult's perspective.

It is fair to say that there has been significant research with younger children, but that there is little agreement regarding the influences of 'nature' and 'nurture'. There are corresponding uncertainties about the reasons children often appear to lose interest in spontaneous art activities by the age of 7 to 9 years old and the effects on children of premature instruction. There has been little research with older children.



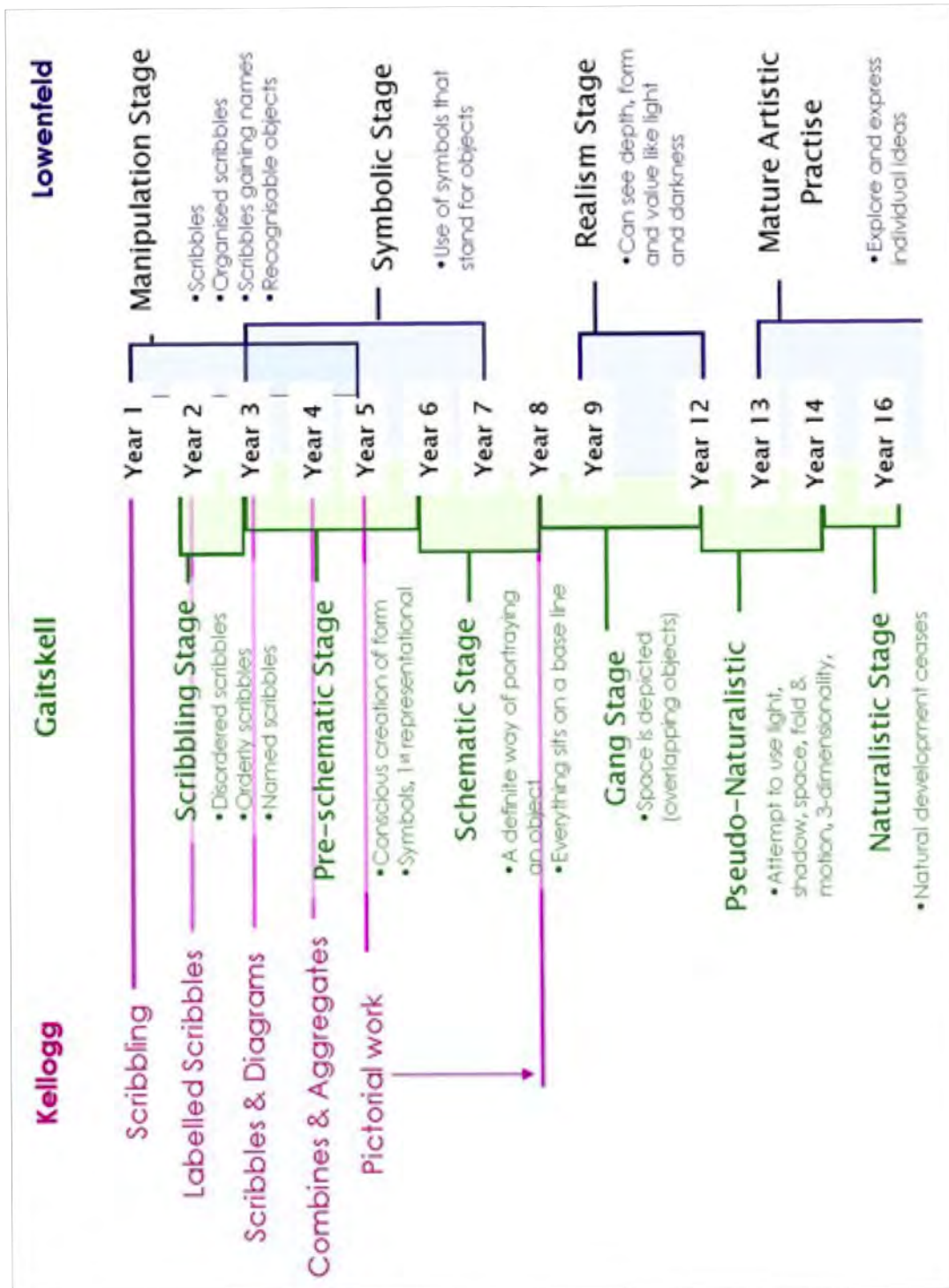


Figure 2. Kellogg, Gaitskell and Lowenfeld's developmental stages

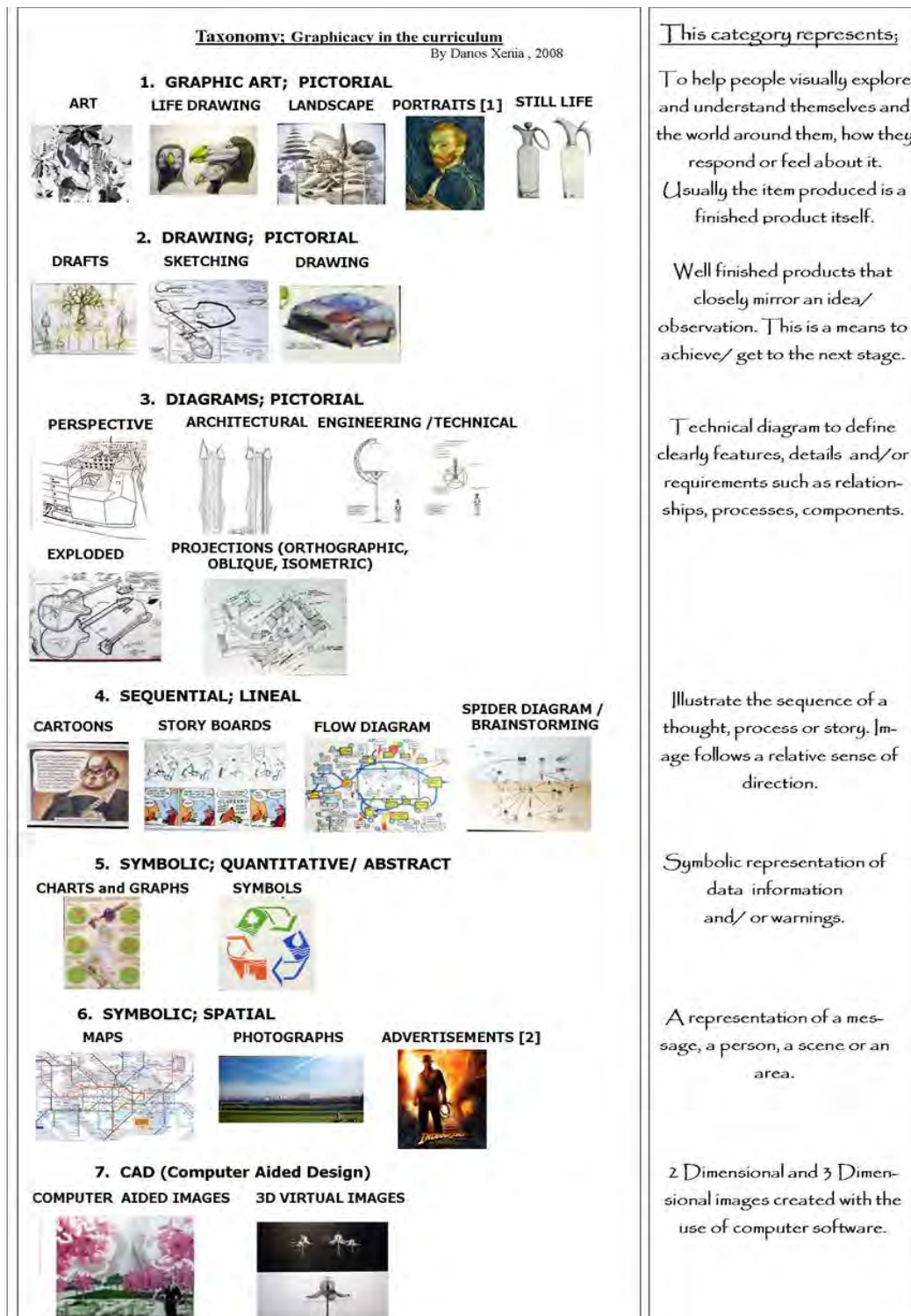


Figure 3. A taxonomy for graphicacy

**Research strategy for exploring continuity and progression in graphicacy**

Making significant progress in such a large research area depends crucially on taking a systematic approach. Consequently a taxonomy of graphicacy for use as an analytical tool within research in secondary education has been developed from both literature reviews and analyses of image use in school curricula (Danos & Norman, 2009; Danos & Norman, 2010).

Three case studies based on the analysis of textbooks have been conducted in secondary schools in Cyprus, the UK and the USA. The main purposes of the studies were to identify graphicacy across the curriculum and to test the taxonomy from an inbound perspective as used within secondary education. Furthermore, the study identified the subject areas related to particular aspects of graphicacy (Danos & Norman, 2010) and has indicated that graphicacy is very widely used in all the subject areas analysed. Curriculum links were also identified (Table 1), as well as common teaching and learning purposes across the curriculum (Table 2).

**Research methodology**

The taxonomy of graphicacy is composed of 24 areas which need investigating to define continuity and progression. This study will be focused on Key Stage 3 (KS3). A range of different methods could be adopted to establish the descriptors for each area:

- Analysing tasks
- Analysing books
- Observing teachers
- Interviewing teachers
- Focus groups
- Co-research
- Delphi study

It would be expected that teachers have significant tacit knowledge and expertise in relation to graphicacy and that this could be embodied in the tasks they set and the textbooks they influence. It would be expected that aspects of such knowledge could be captured by direct analysis, and could be confirmed through observations, interviews, focus groups or a Delphi study. These possibilities are explored here by discussing the analysis of tasks and a Delphi study. The further possibility of co-research to accelerate the process is then presented.

From the pictorial, sequential, symbolic and CAD categories	From the additional category entitled 'Other'
Gain familiarity and place new knowledge into context Support embedding new knowledge Provoke interest Spark conversation Illustrate students' ideas, knowledge and understanding Image used for visual stimulation Visual representation of information/data Test students' knowledge Test students' understanding Exploration, research, understanding	Organise information Learn through play

Table 2. Common learning and teaching purposes relating to all areas of the taxonomy

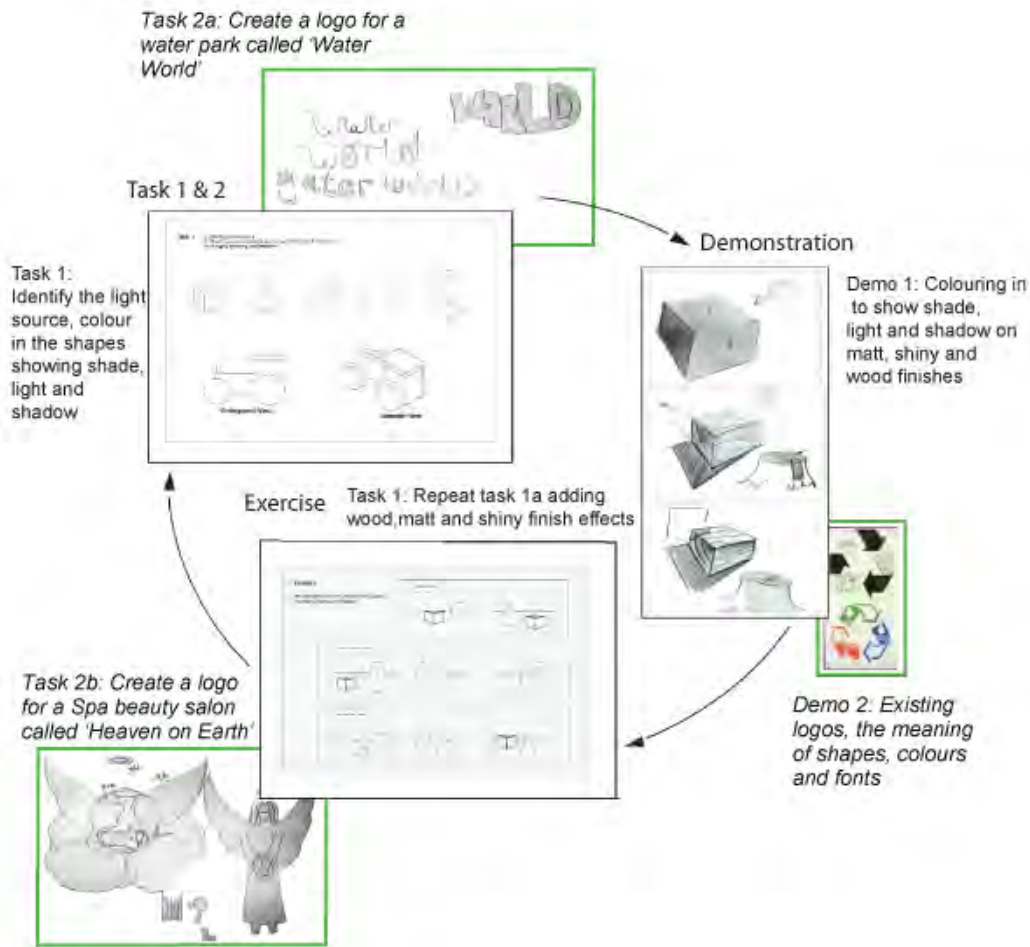


Figure 4. The sequence of the lessons for rendering (task 1; typed in normal font) and symbolic representations/ logos (task 2; types in italics)

**Analysing tasks**

This methodology has been developed and trialled during a case study completed at Loughborough University (Danos et al., 2010). A group of 24 Year 10 students (around 14 years old) took part in a workshop designed around the students' academic needs. The students were in their first year of GCSE, studying product design, resistant materials or graphic products. Three areas of the taxonomy were looked at during this study, to develop and finalise the methodology. These were:

- Pictorial (category): Drawings (subcategory): *Perspective*<sup>2</sup>
- Symbolic (category): Abstract (subcategory): Symbols - *logo design* (Figure 2)
- Pictorial (category): Art (subcategory): Life drawing – *rendering* (Figure 2)

The methodology followed for each session (for each area of the taxonomy) was designed in a similar manner (Figure 4).

<sup>2</sup> The focus of the tasks set in the particular area of the taxonomy are shown in italics

1. In order to create an individual record of progression for each student, students were asked to complete a task before the theory was delivered on any technique. They were told what to do but no explanation was given on how to do it.
2. Theory along with demonstrations and exercises were delivered, and students practised implementing the new knowledge. The exercises increased in difficulty and complexity as the session went on, to ensure gifted and talented students were equally challenged. This also provided some indications towards the limitations of skills and abilities of that group of students.
3. A final task was given in a similar way as the initial task, to complete the individual records of progression. Analysing data: Completed tasks were scanned and the originals returned to the students with relevant feedback on future progression goals. The virtual copies were saved by replacing each student's name by a code identifying the relevant session, task number, year group, date of completion, gender and number of participant. Once the comparative analysis between students' work was completed, a list of descriptors for continuity and progression was drawn (Table 3). The number of students achieving each descriptor was then counted in order to explore the possibility of sequences in the data.

<b>Rendering list descriptors</b>			
	<b>Students' work</b>		
	Student 1		
<b>Tasks</b>	1a	1b	1c
Identify a light source	/	/	
<b>Rendering</b>			
All visible surfaces coloured in		/	
All visible surfaces coloured in using the correct tone	/	/	
All visible surfaces coloured in using the correct gradient		/	
Gradient of colour applied in a smooth form where appropriate		/	
Shading to suggest the correct form/ shape of the object			/
Shading drawn to suggest a specific finish i.e. wood, matt, shiny	n/a	/	n/a
<b>Shadow</b>			
Shadow added		/	
Shadow added at the correct direction		/	
Shadow coloured in using a gradient			
Shadow coloured in using the correct gradient			
Shadow added to suggest the correct form of the shape		/	
Shadow added correctly according to the distance of the light source			

Table 3 Rendering: analysis of students' work

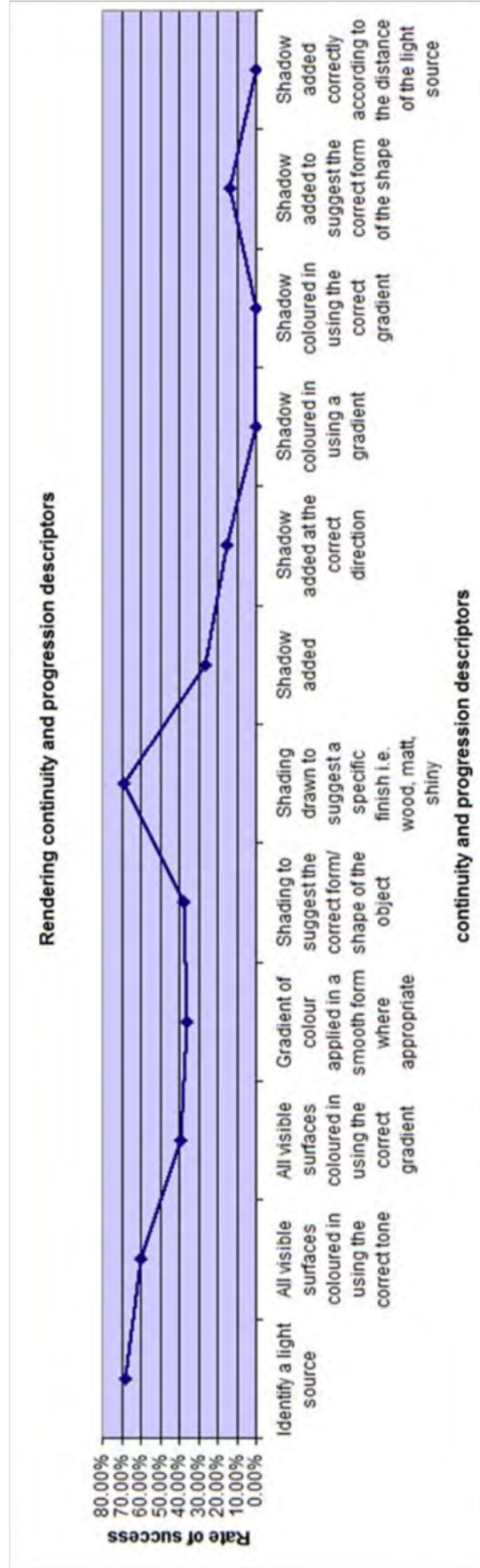


Figure 5. Rendering: rate of successfully completed level descriptors

Figure 5 illustrates the progression descriptors of the students according to the descriptors for a rendering task, indicated during a pilot study (Danos et al., 2010).

The case studies have established this as a successful methodology for the research.

**Delphi technique**

The Delphi method is considered to be a systematic interactive forecasting method formed by a group of experts, ‘effective in allowing a group of individuals to solve complex problems’ (Linstone & Turoff, 1975:3). It is based on the assumption that group judgments are more valid than individual judgments. Experts are asked to give their opinion (otherwise known as ‘forecasts’) on the issue at hand, which is clearly explained in an appropriate form, varying from questionnaires to open questions. Answers are collated; processes and any irrelevant comments are filtered out. Common and conflicting

A collaboration with a secondary school has been developed to enable other areas of the taxonomy to be studied. Current schemes of work have been analysed, covering the subject areas of graphic products, resistant materials, systems and control, textiles, food technology, art and ceramics and appropriate tasks developed. viewpoints are identified. The outcome is then sent back to the experts who comment on their own forecasts, the responses of others and on the progress of the panel as a whole. Results are processed again by the panel director and sent out for further review (Figure 6). This avoids the negative effect of face-to-face panel discussions and solves any group dynamic issues. Usually all participants maintain anonymity which allows them to freely express their opinions and encourages them to openly critique and admit errors by revising earlier judgments. Participants were mainly from UK, Cyprus and the USA.

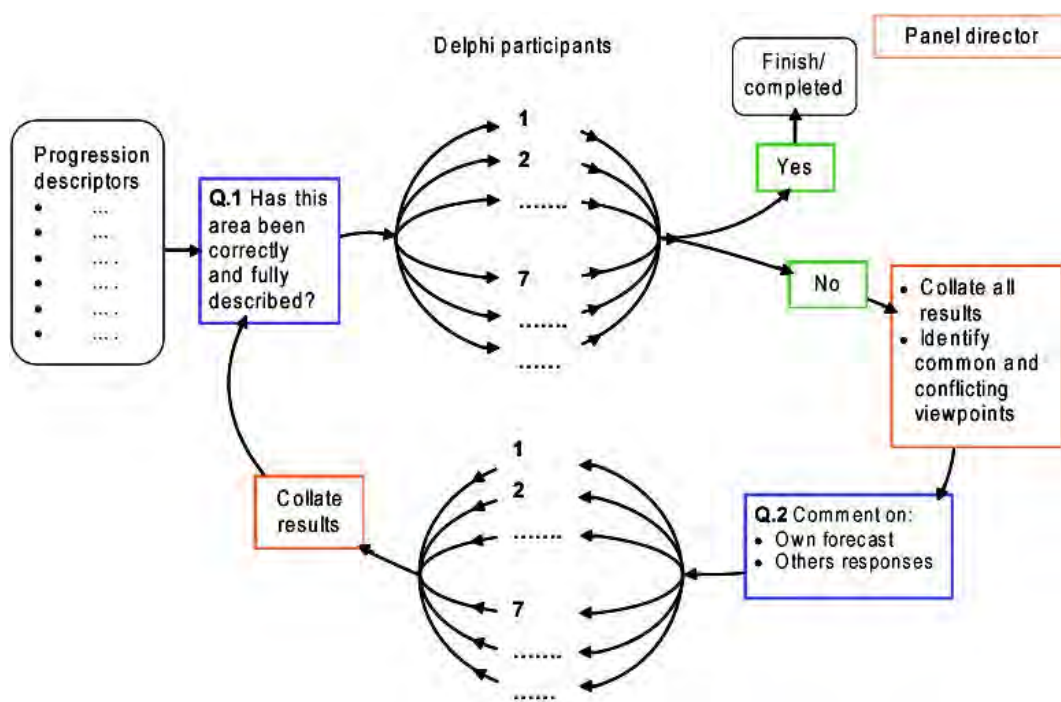


Figure 6. Visual representation of the Delphi technique

**Co-research**

The initial pilot studies on defining level descriptors brought to the surface the time requirements and dedication needed to achieve accurate and detailed results of continuity and progression level descriptors of graphicacy. For this reason, the possibility of working with other researchers in order to investigate some of the areas has been considered and deemed appropriate. The areas to be studied using this method were chosen according to the possibilities available at the time a co-research partnership developed.

Working with other researchers while the author was still focused on this study had the advantage of helping and guiding the interested researchers in pursuing this area. This allowed co-researchers to produce reliable results in a form that could be used and collated with this project. PGCE<sup>3</sup> students were targeted for

co-research since they were required to undertake action research as part of their teacher training programme (Danos et al. 2010). This was used as a pilot study to test this methodology. In some instances, results from this co-research failed to capture the necessary depth of detail required; in others, the data were incompatible. However, new ideas were generated for tasks as well as identification of possible issues that could be looked into in the future (Figure 7). For example gender differences, age, punctuality etc.

Co-research could be organised to gather data on graphicacy within school curricula as well as to facilitate graphicacy audits as indicated in Figure 8. Through such a scheme, sufficient sample sizes for statistically determined levels of student performance could be established. These could be based on either teachers' experience or expectations, or from actual results taken from student's work.

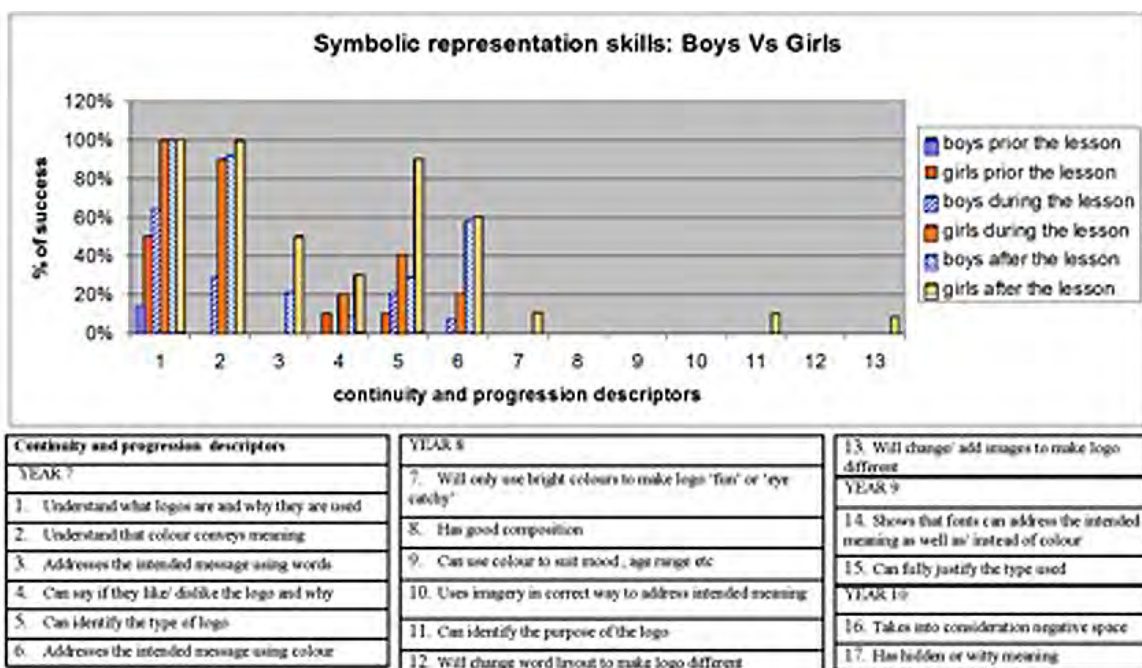


Figure 7. Symbolic representation skills; Gender differences (adapted from work by Sam Lyne)

<sup>3</sup> Postgraduate Certificate of Education



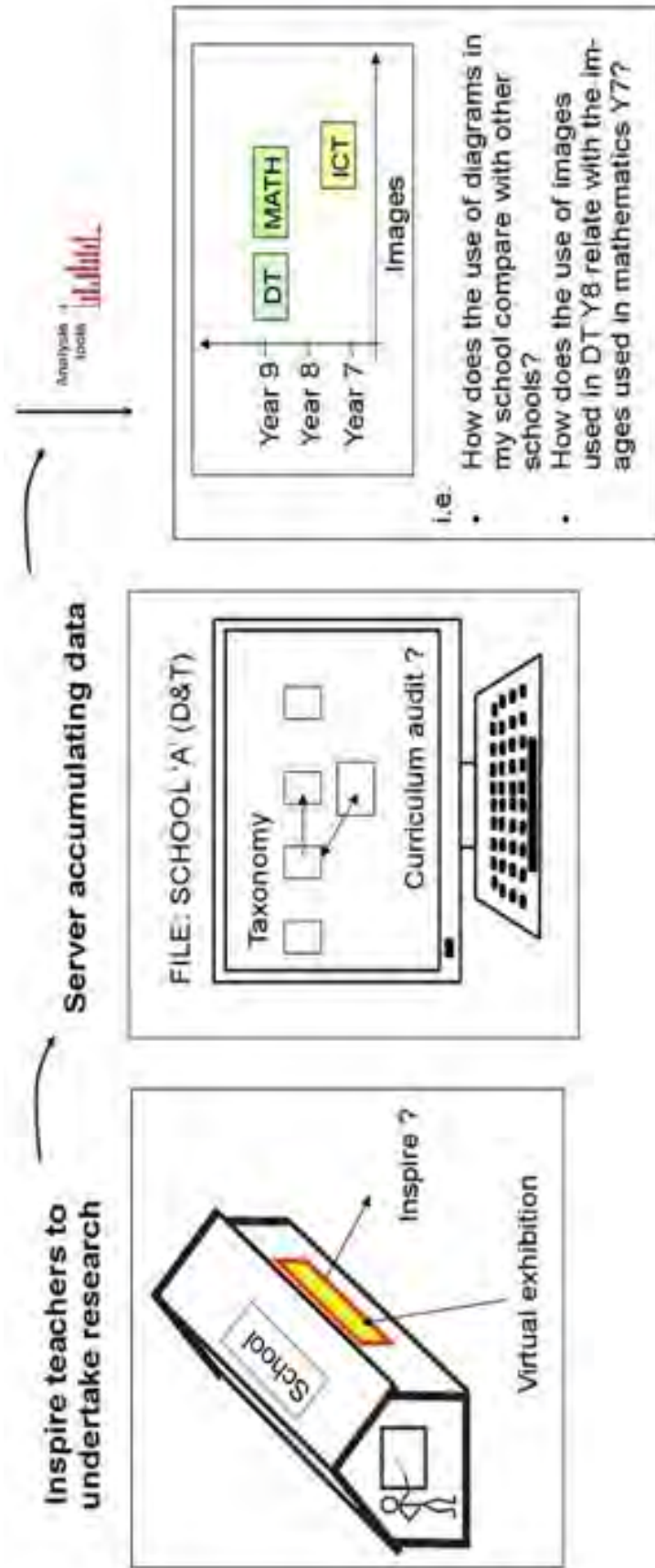


Figure 8. Co-research: gathering collectively information

## Concluding discussion

Detailed work has been found in regards to early childhood mark-making and drawing development, with well-defined and described stages drawn from research. Academics, scientists and other authors have described stages children go through during the years from 11 -14 covering different aspects of development, but the information found has been rather vague. Detailed work focused on that age range could be very beneficial to both educators and the research community.

The literature review suggests a lack of understanding and clarity as to where nature stops and nurture takes over. Strong indications are provided however, as many authors agree that around the age of 8 years old children have to 'make an effort to learn how to draw', or else they 'give up drawing'. This might be a primary reason as to the reason developmental stages and progression becomes very vague around and after that age. However, no empirical evidence has been found to support the above view.

Some of the key areas of agreement within the work reviewed were:

- the progressive direction and artistic ability of children develops with age
- children have an internal model from which they extract knowledge when drawing, which in many children appears to be very similar at similar ages.
- artistic development never develops in one direction or in a constant order due to cultural and educational aspects (Luquet (1927), Lowenfeld (1947), Harris (1971))

- it is possible for children to 'skip' some of the initial stages such as the random scribbling and simple diagrams. (Harris (1971), Balchin (1966), Golomb (1992).
- children (below 8 years old) produced drawings that emphasised known facts about the object, whereas older children can draw objects as they are set in front of them correctly illustrating their viewpoint
- Piaget believed that young children are self-centric
- children lose interest in spontaneous art activities by the age of 7 to 9 years

Some significant contradictions found within the work reviewed were:

- children between the ages of 6 to 10 do not have the ability to express mood with colour or lines. There is no evidence to suggest that children can use or have the advanced intellectual concepts which are needed for abstract thinking about symmetry, prop-ortion or rectangularity (Winner (1982), Arnheim (1974), Kellogg (1970), Schweizer (1999), Edwards (1993), Harris (1971))
- the hypothesis that differences of representation in children's drawings may come from the difference of aesthetic to which children are accustomed (Golomb (1992).

The literature review has revealed this to be a research area in need of major efforts and systematic approaches. A taxonomy for the analysis of graphicacy has been presented and the outcomes of its use in 3 case studies in schools in Cyprus, USA and UK have been noted. Cross-curricular links as they emerged from the case studies were described, along with common teaching and learning purposes for which the images were used. The most pressing need seemed to be for identifying continuity and progression (CaP) descriptors for graphicacy and a number of research methods suggested.

Task analysis has been piloted and demonstrated to be an effective approach for developing CaP descriptors. Co-research has also been piloted and, although it did not result in further CaP descriptors, its potential for providing greater reliability for the findings was evident. Data could be collected through these and other methods, such as observations, interviews and focus groups, and its validity significantly increased through a Delphi study. As there is a great deal to be done to make inroads into the research agenda, research methods that allow researchers to collaborate and share their findings need to be established.

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## The elephant in the room: the influence of prevailing pedagogical practice on the integration of Design and Communication Graphics in the post-primary classroom

Oliver McGarr

### Abstract

*Senior Cycle Technology subjects in Irish post-primary schools have recently been updated. One subject, Technical Drawing, has been replaced with a new subject called Design and Communication Graphics (DCG). The new subject is quite different in content and is also quite different in its focus highlighting an emphasis on communication and design. This paper aims to explore the influence of prevailing pedagogical practices on the integration of the new DCG syllabus. The paper firstly examines the current pedagogical practices within Irish post-primary classrooms before moving on to discuss some of the emerging challenges and opportunities in light of this evidence. The paper argues that without challenges to prevailing societal attitudes towards technology education in schools it is unlikely that the changes in pedagogy required to fully embrace the philosophy of the new syllabus will be achieved.*

### Introduction

The suite of technology subjects in Irish post-primary schools has recently undergone considerable changes. These changes mark a shift from the traditional focus of the subjects, aimed at developing

craft skills and technical competence, to one that focuses on the development of transferable knowledge, skills and attitudes. This shift mirrors an international move 'from the transmission of facts or the demonstration of skills towards the development of active, autonomous learners' (Dow, 2006: 309).

This paper aims to examine the challenges to this curriculum change in the Irish post-primary education system and in particular in the context of the new subject of Design and Communication Graphics (DCG), the replacement to the Technical Drawing curriculum. The paper firstly aims to explore the current pedagogical practices within Irish post-primary classrooms before exploring the influence of these teaching approaches on the subjects of Technical Drawing. Following this, an exploration of the new philosophy and thinking behind recent curriculum changes will be outlined. The paper then aims to discuss some of the emerging challenges and opportunities which lie ahead and attempts to highlight possible outcomes of these ongoing changes.

**Pedagogical practice: from content to experience**

Technology education has always faced the challenge of keeping abreast with emerging technologies and practices. The history of most technology curricula are dotted with changes to subject content, influenced by the emergence of new technologies. From the development of the microprocessor to the growth of computer-aided design (CAD), technology education has tweaked and changed the content of syllabi to incorporate these elements. These changes reflect the traditional vocational nature of technology education where preparation for the specific sectors of industry and business was a high priority. However, while in general syllabi have adopted changes in content, pedagogical approaches have

remained the same. Current international attempts to reform technology education have been driven by concerns over the prevailing pedagogies used as much as the relevance of course content. Owen-Jackson (2000) notes that from their inception, all technological subjects at post-primary level were *'concerned only with the passing on to pupils traditional knowledge and skills [where] Pupils were required only to learn the knowledge, not to understand it, and to copy and practise the making skills'* (p. 5). Banks (2000) notes that this was achieved by adopting a pedagogy *'not so very different to the 'master-apprentice' model of the medieval guild'* (p. 151). These practices remain influential today (De Vries, 2002) and reflect the historical emphasis on developing knowledge from experience. However teaching strategies focused on

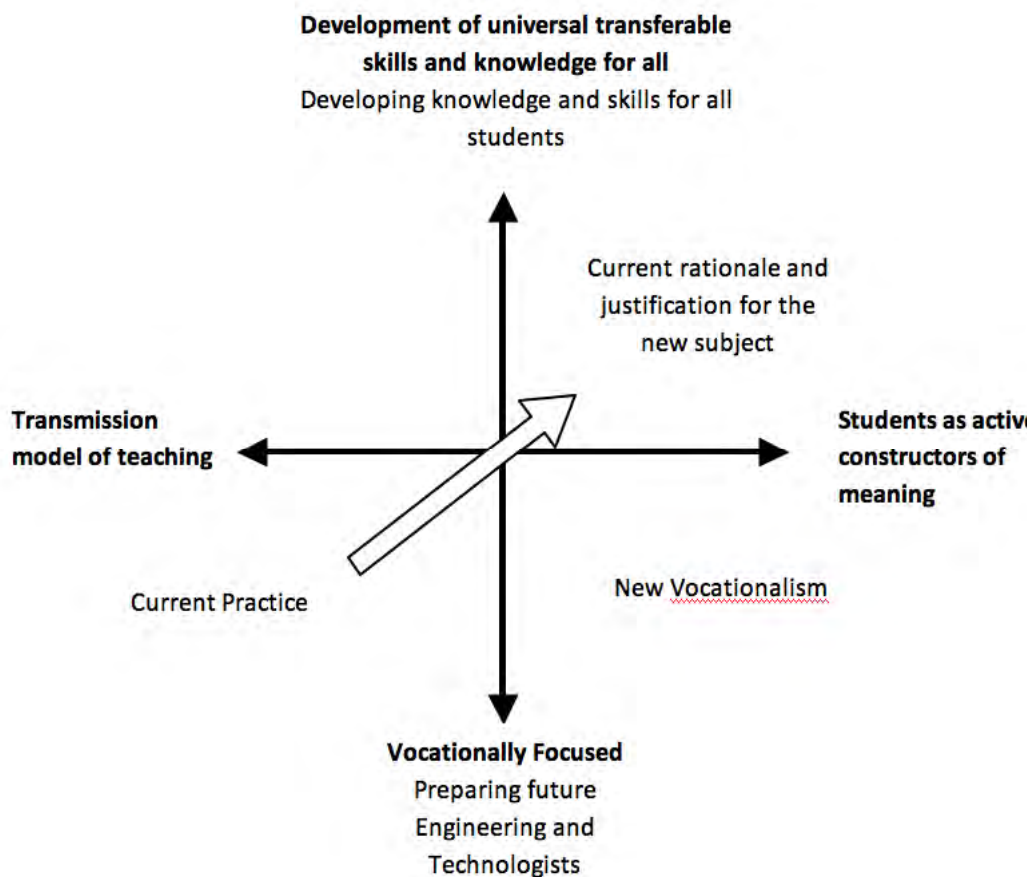


Figure 1. Shift in thinking

experiential learning, where the knowledge acquired is seen as tacit, are increasingly being called into question since there is an absence of critical engagement and a deep understanding of the practice. These approaches are also seen to encourage passivity and conformity rather than encourage creativity and critique. Writing about the influence of this type of pedagogy Dakers (2005a) writes that;

... learning in this narrow model is linear and instrumental and to all intents and purposes, not meaningful learning at all. It is more concerned with the assimilation of the young into an already established value system which has more to do with control than it has to do with liberation.

(p. 113)

*authentic and meaningful learning experiences*' (Dow, 2006: 307) through the integration of more collaborative practices. Such approaches place a premium on problem solving, critical thinking, teamwork skills and creativity. In this context the role of technology education is not to pass on a set of technological skills transmitted in a behaviourist mode (Dakers, 2005a) but to create experiences where students can engage as autonomous learners solving real-life problems on their own or in collaboration with their peers. This process is supported by relevant technological tools and artifacts and the solutions are carefully considered with cognisance of their potential social and environmental impact (McGarr, 2010). It could be argued that the creation of these types of learning experiences free technology related subjects from their initial vocational focus since exposure to this type of practice can develop important transferable skills for success in life regardless of the careers chosen by students. On the other hand, it could also be argued that such approaches are a new

form of vocationalism equipping students not only with the technical knowledge but also with the broader transferable skills needed in industry today. Figure 1 below outlines this shift in thinking.

Regardless of the underlying rationale for these changes, '*changing pedagogical practice in technology and science within the European context will clearly not be an easy task*' (Dow, 2006: 319). In exploring best practice in science and technology education across Europe Dow (2006) recognised the conserving influence of prevailing pedagogical practices, not only on curriculum reform initiatives, but also on newly qualified teachers that may enter the teaching profession with alternative understandings of the value and purpose of technology education. This thinking may be quite different than the thinking underpinning reform attempts. Hansen (2008) also highlights the conforming influence of past experience on teachers practice;

Most general studies teachers adopt some variation of a transmissive model for teaching. Such teachers believe, partly as a result of their university training and partly out of conditioning from their own schooling, that learning in schools is exclusively about "knowing" rather than "experiencing". They perpetuate a system of teaching into which they were successfully indoctrinated when they were students in high school.

(p. 195)

In this context it is worth exploring the prevailing pedagogical context within Irish classrooms in order to examine its possible influences on recent changes in curricula to the suite of technology subjects at post-primary level.



### **Pedagogy in the Irish post-primary classroom**

Concerns have been raised for several decades about the nature of teaching and learning in Irish post-primary schools. These concerns highlight the dominance of a transmission model of learning with little emphasis on evidence-based methods. While research into classroom practice is limited, the studies that have been conducted all consistently report similar practices. One of the earliest insights into classrooms, conducted by the OECD in 1991, found that teaching and curriculum were largely determined by examinations requirement and that there was a strong emphasis on 'a didactic approach' (OECD, 1991: 55). Later in the decade, research by Callan (1997) into the use of active learning, a key element of the Junior Certificate programme, found that despite the emphasis on active learning methodologies outlined in the new curriculum, practices remained largely teacher centered. Similarly, research by Mackey (1998) into post-primary classrooms found that classrooms were dominated by teacher talk and that;

Pupils were expected to work independently and to remain silent apart from when responding to a teacher's questions. On occasions during Science practicals pupils did work together, this was not done to promote deliberate interaction between pupils, as pupils were directed on the procedures to be followed and were admonished for talking to one another. Apart from these Science practicals, group work did not feature as a classroom/teaching strategy. Each class was taught as a whole group unit.  
(p. 288)

Mackey concluded that teaching subject content was the main concern of teachers

and that 'teaching methodologies they employed aided lower to middle level cognitive development' (p. 290)

A large-scale study by Lyons et al (2003) into how pedagogical styles impacted on students' attitudes to, and experience of, learning mathematics, found very similar teaching approaches. The research found that there were three prevailing themes in teachers' discourse in the mathematics classroom. The first was a preoccupation on teaching for examinations, secondly maths was presented as being either hard or easy and finally students' answers to questions were defined as being right or wrong. In describing the nature of the teachers' pedagogical practice they noted;

Classes were strongly teacher directed, with teachers generally using a didactic approach to the presentation of material. Teacher initiated interactions with students comprised 96 per cent of all public interactions in the twenty mathematics classes observed. Teachers were far more likely to use lower order than higher order questioning, and to use drill and repetition rather than discussion-type questions, to teach mathematical concepts. The work programme of the class therefore was strongly teacher determined, with a resultant lack of student participation in the organisation of their own learning.  
(p. 147)

In a similar vein, the most recent research, the international OECD Teaching and Learning International Study (TALIS) report on Ireland, published in 2009, found that 'Teachers in Ireland were somewhat less supportive of constructivist beliefs, and somewhat more supportive of direct transmission beliefs than their counterparts in all five comparison countries' (Shiel et al, 2009: 6).

### **Pedagogies in the drawing studio**

The high level of consistency across these studies suggests that this teacher-centred transmission model of learning is deeply embedded in practice and common across most subjects. It has been argued that technology subjects tend to be more student-centred, since students are constantly challenged with the design and manufacture of an artefact. However this has not been the case in the traditional Technical Drawing subjects where the teaching approaches tend to focus on a more teacher-centred transmission model. In general terms the teaching approach adopted in these drawing labs have their roots in the past. The original subject of mechanical drawing was originally established in the vocational school system in the 1930s to prepare students as draughtsmen. In this context the role of the subject was to develop a high level of neatness and accuracy in the completion of quite abstract graphical problems. Very often the completion of the 'problem', rather than a deep understanding of the concepts and principles that underpinned the solution, was seen as the goal of the exercise. A 'show and copy' approach was seen as the most effective teaching method to achieve such an outcome and therefore such teaching approaches became deeply embedded in the subject. In addition to the nature of the subject in Ireland, vocational schools were largely associated with economic and social disadvantage as well as with preparation for manual employment (Trant and Geaney, 2000). Although these schools are now integrated into the mainstream post-primary school system (and indeed many have amalgamated with secondary schools in their locality) they nonetheless maintain many of the historical residues of the past. For example, the technology-related vocational subjects

continue to be dominated by males and continue to attract a greater proportion of students from lower socio-economic backgrounds. In many schools they continue to be seen as subjects for the 'less able' students, as preparation for manual employment and as an alternative to more traditional 'academic' subjects. Such views of the subjects, and of the students studying them, have also contributed to an absence of critical engagement with course content. Trant and Geaney (2000) also note that vocational education has low prestige because it is perceived as lacking the qualities traditionally associated with the more traditional classical liberal education. Within schools where vocational subjects compete with the more traditional liberal subjects similar comparisons are made.

### **DCG and the new philosophy**

The new Design and Communication Graphics (DCG) syllabus, launched in 2007, was not significantly different than its predecessor, Technical Drawing, in terms of its content but the rationale for its inclusion on the curriculum was quite different. Rather than the vocational justification of the Technical Drawing course, the new syllabus set the subject in a much broader context linking it as an important part of a broad comprehensive educational experience for the student. It also recognised the contribution the subject could make in the development of a broader set of skills and competencies;

The Design and Communication Graphics course makes a unique contribution to the student's cognitive and practical skills development. These skills include graphicacy/ graphic communication, creative problem solving, spatial abilities/ visualisation, design

capabilities, computer graphics and CAD modelling. (NCCA, 2007: 4)

Having at its centre a focus on design and communication was a marked change from technical drawing. This change in emphasis was also accompanied by the inclusion of a significant CAD component on the new syllabus.

**Challenges to integration:  
prevailing 'folk pedagogies'**

As with all attempts at curriculum reform, change is complex and in many cases the actual outcomes of the change process can be very different than the intended goals. In relation to the new DCG syllabus, and its focus on shifting the subject to a more design orientated experience, the process of change is complicated by parallel attempts to upgrade course content with the latest technological advancements. In light of the prevailing pedagogical practices within the traditional drawing studies, what impact will the proposed changes have in the long-term? Will it be seen as a slight computerised approach to existing practices? Is it realistic to expect that the substantive changes in the focus of the subject will be achieved? What, of value, may be left behind during this curriculum change? What happens when one maps on proposed changes in pedagogical approaches to an existing transmission model of practice? Dakers (2005b) outlines the influence of prevailing 'folk pedagogies';

Whilst some teachers may accept the received wisdom of policy makers, a considerable number will subvert policy to suit their own particular implicit theories, based upon their own interpretation of the meaning of technology and thus, technology education. These deviations from

policy may be based upon their own implicit beliefs about what constitutes technology education in particular, or even education in general. For example, a rationale for technology education may espouse, as a central tenet, the need for creative enterprise. However, the adoption of this rationale may be problematic for some teachers depending on their implicit theories, not only of technology, but of creativity in particular and learning in general.

(Dakers, 2005b: 76)

Teachers' existing pedagogical practices are informed by their knowledge of the subject, the pedagogical skills they possess and their beliefs and attitudes towards education and in particular their specialist subject areas. Knowledge and skills can be addressed through appropriate professional development and in-service activities; however, challenging deeply held beliefs that underpin practice is more complex. Past programmes of in-service paid little attention to beliefs and attitudes. Dow (2006) for example notes that in relation to technology education, teachers' underlying assumptions about the nature of effective teaching and learning has been given insufficient attention by policy makers in the past. Many in-service programmes have operated on the belief that through exposure to the practices associated with the new syllabus the pedagogical practices would be incorporated into teachers' practice. This perspective sees the 'mechanical' adoption of these practices as leading to deep and meaningful changes in beliefs and attitudes. Over time it is believed that the teachers' practices will begin to align with the philosophy of the intended changes.

Yet there is little evidence to support this view. For example, research into previous

attempts to embed active learning with the Junior Certificate has shown that teachers can subvert and neutralise the intended changes. In exploring the use of active learning in the Junior cycle 7 years after its launch, Callan (1997) found that while changes in the content of the Junior Certificate programme were implemented, the pedagogical approaches that accompanied the changes, namely an emphasis on active learning, were not implemented.

Folk pedagogies do not exist in vacuums. They are informed and sustained by the prevailing beliefs and attitudes of both teachers and society. These include beliefs held by teachers in relation to the rationale for the inclusion of the subject on the curriculum, teachers' beliefs in the purpose and value of the subject and beliefs about who the subject is for. Similar beliefs exist within society where it continues to be seen as a masculine subject and suited to more 'non-academic' students and those that are increasingly more disengaged with school. Challenging these beliefs requires a strategy that focuses on challenges societal assumptions as much as the professional development of teachers. From the teachers' perspective future professional development opportunities therefore need to raise awareness of the role played by the subject in developing important transferable design, analytical and problem solving skills. Practicing teachers need to have knowledge of how the subject can contribute to the development of these skills and how different strategies and pedagogical approaches can facilitate their acquisition.

From a societal perspective, changing the public perception of these subjects is a critical task in raising the status of the subject. The subject of DCG, and at a wider level all technology subjects, need to

be portrayed as an educational experience for all students and a vital part of a broad comprehensive curriculum. At present it appears to have a low status within the education system. For example, while concerns are expressed nationally and internationally about the low uptakes in science and technology, initiatives to address this problem primarily focus on uptake of maths and science. There is however a growing recognition of the educational value of technology education as reflected in the increasing research in this area in Ireland. This research will play an important part in highlighting the educational value of such subjects as part of a broad and balanced educational experience for students. The increasing research output can also inform practice and ensure that future policy, and subsequently practices, are soundly evidence-based.

## Conclusions

Technology education, and in particular DCG, has an enormous contribution to make to the post-primary experience of students. As part of a broad and balanced educational experience it can enhance the students' overall learning experience in school and can play an important part in developing visual spatial abilities and nurturing creativity. The subject is also unique in that it provides an educational experience that blends both cognitive challenges with more artistic and creative elements. However, this value of the subject and the potentially unique contribution it can make to the student's learning experience, will not be realised if it is continually viewed through its past manifestation both by the public and teachers. What is required in this context is a complete reconceptualisation of the purpose and rationale for the subject. This process begins with a critique of existing pedagogical practices within the classroom

and the attitudes and beliefs that underpin this practice. Otherwise, 'technology education will remain a narrow and limited curricular area, restricted to the production of a technologically subservient and

compliant underclass' (Dakers, 2005a: 113).

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## What is the role of observational drawing in contemporary art & design curricula?

*Michelle Fava*

### Abstract

*This paper makes a case for the valuing of cognitive and practical function of observational drawing in art and design curricula. Drawing skill is often regarded as tacit in nature, and therefore can be problematic in regard to contemporary assessment practices. The paper identifies a range of cognitive skills inherent in the activity of drawing, arguing that a thorough consideration of drawing and cognition makes possible a more rigorous approach to assessing drawing within existing assessment frameworks. It also calls for a review of assessment practices and frameworks, highlighting the need for a more holistic approach to assessment to be based on contemporary theoretical insights about the nature of learning and cognition.*

### Introduction

How can contemporary theoretical insights about the nature of drawing inform a discussion on curriculum design and assessment?

A decline in the prevalence of drawing in art & design curricula has been noted<sup>4</sup>, but the reasons for this are unclear. Certainly, drawing for 'conventional' purposes is no longer indispensable, but maybe this shift can allow us to examine more subtle aspects of drawing skill. Such an examination would be valuable in an educational climate that required being explicit about learning outcomes. Recent empirical findings and new theoretical

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<sup>4</sup> Concerns about a general decline in drawing ability have been expressed; Alsop (2002); Rose, Jolley & Burkitt (2006); Jolley (2009). Observational drawing has been reported as "not really part of many/most curricula across the UK anymore" (Leo Duff 2010, personal communication). A more general trend has also been noted, "whereby practical, situated and embodied knowledge, once so central to the study of art and design in Higher Education, has since the late 1960's become more peripheral" (McGuirk 2008).

insights in cognitive psychology are allowing an enhanced understanding of drawing, which might be useful in informing and making explicit the way we conceive of drawing.

This paper invites opinion and discussion about the place of observational drawing skills in contemporary art & design curricula in further and higher education. In what ways is it still valuable to students, how does it fit with contemporary notions of graphicacy, and how should this be reflected in curriculum design and assessment practices?

Personal communications with drawing practitioners will be used to illustrate commonly held beliefs about observational drawing and the wider abilities it enables<sup>5</sup>. Cognitive and 'second generation' embodied-cognitive perspectives on learning will then be considered and I will make some tentative proposals about an expanded definition of drawing skill.

One reason (among many) for the perceived decline of observational drawing might be a clash between a practice which is largely tacit, embodied, non-verbal and growing institutional imperatives to make learning explicit in the form of outcomes, level descriptors and assessment criteria. It is important that such requirements do not serve to marginalise tacit skills like drawing, which risks relegation to a supporting role in other learning activities, if it cannot compete with more explicitly measurable skills.

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<sup>5</sup> The author would like to thank Leo Duff, Rachel Pearcey, Eduardo Corte Real, Lisa Moriarty, Doris Rohr and Richard Hare for their contributions and insights in response to questions sent through the DRN mailing list.

Here we will consider how a contemporary understanding of cognition might help address drawing more directly in assessment practices, but the limitations of such practices will also be considered.

### **Practitioners' views on the purpose of observational drawing**

Jane Tormey (1997) observed, "in all the recent debate there seemed little articulation of how drawing methods may be relevant, or to the nature of activity and why it was important". This paper asks what is it about *observational drawing* that can be considered of continuing value to art & design students?

Debates exist around the place of manual design drawing after the advent of drawing software<sup>6</sup>, and around the relevance of representational drawing in contemporary fine art practice. Aside from these ongoing, changeable debates lays a broader assumption that observational drawing enables a range of transferable skills.

In a review conducted by Tormey, Foundation Art and Design tutors most frequently valued drawing as, "underpinning and essential", "the means of analytical learning", "the means to improve perceptions, visual awareness and manual skills" (1997).

"It was suggested that drawing is "the ultimate transferable skill" and encourages the ability to adapt. It provides the progression from research, through analysis and speculation to solution. It progresses visual thinking" (1997).

The debate:

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<sup>6</sup> For a detailed analysis of the role of digital and manual drawing in design see Garner (1999), Johnson (2005), Prats et. al.(2009).

“illustrated [...] the need to balance activity which is designed to provide real learning through the *process* of drawing, with the kind of drawing activity that is likely to generate more obvious and *visible skill* acquisition because the methods are recognisable” .

(1997, emphasis in original)

However, It is unclear what exactly is meant by ‘real learning through the *process*’, or what exactly is (or is assumed to be) the nature of the ‘visual thinking’ enabled by observational drawing.

Drawing practitioners describe the purpose of observational drawing in many ways: “to understand the engineering structure and texture of objects, human beings, environments” (Rohr 2010, personal correspondence). “It sharpens observational skills generally” (Hare 2010, personal correspondence). “[S]tudents need procedures of inquiry that help them to understand/criticise the existent“(Corte-Real, 2010, personal correspondence).

Echoing Ruskin’s (1991[1887]) dictum that to learn to draw is to ‘learn to see’, Leo Duff describes the purpose of observational drawing as “to look, to see, to focus, to concentrate, to sustain your concentration”. In her opinion, observational skill enables “decision making, clarity of vision” (2010, personal communication).

A consideration of learning and cognition can demystify these beliefs, showing that ‘real learning’ can be visible in observed drawings. Furthermore, a consideration of the relationship between perception and cognition can inform approaches to teaching and assessment.

### Existing assessment practices

The Quality Assurance Agency benchmark statement for Art & Design (2008) does not mention specific outcomes. These date quickly and are left to the discretion of the institution. However, a wide range of generic and transferable skills are cited, including a requirement for ‘particular cognitive attributes’ (2008: 3). Drawing skill is regarded as comprising the full spectrum of cognitive activity: “a prerequisite skill for observation, recording, analysis, speculation, development, visualisation, evaluation and communication” (2008:5). There is no indication of where observational drawing is assumed to fit with this description, but these guidelines indicate general descriptors that might be used to assess drawing. QAA (2006) codes of practice require explicit verbalisation of learning outcomes<sup>7</sup>. This is regarded as restrictive by some as there are limits to verbalising creative learning (Dentith 2002, Orr 2010, Gordon 2004), but guidelines are open ended enough that institutions can devise learning outcomes as they see fit.

The situation in FE is somewhat different as unit outlines are written by external awarding bodies<sup>8</sup>, Edexcel being one of the

<sup>7</sup> These stipulate that “Institutions have transparent and fair mechanisms for marking and for moderating marks” (QAA 2006: 31) and that these be written and made available to the student. Modules are expected to have clear learning outcomes, assessment criteria based on these outcomes, and descriptors which “indicate how well the assessment criteria have been met” (QAA 2006: 39). Furthermore, institutions must evaluate “the extent to which assessment tasks and associated criteria are effective in measuring student achievement of the intended learning outcomes of modules and programmes” (QAA 2006: 8).

<sup>8</sup> Another factor here is that FE funding imperatives push achievement, and therefore assessment criteria, to the forefront of institutional strategies and teaching methods, perhaps sometimes unhealthily so.



largest for vocational courses<sup>9</sup>. It can be said that their unit specifications do not reflect the wide range of purposes drawing is ascribed by the practitioners above. Of the 137 BTEC National Diploma units Edexcel currently accredit, none mention drawing in their assessment criteria. Until 2006 there was a unit named 'Drawing Development', since renamed 'Visual Recording'. Standard drawing texts are suggested in this unit's reading list, but drawing is not necessary to pass it. To gain a distinction in this unit a student must be able to:

demonstrate independence, innovation and individuality in evaluating and using sources, integrating visual recording skills and in-depth understanding in communicating information."<sup>10</sup>

(Edexcel 2009: 4)

While this criterion refers to valuable skills, it does not refer directly to drawing. The situation in First, Foundation and Higher National Diplomas is similar. The act of 'recording visually' (be it drawing, photography or otherwise) is relegated to only one of four pass criteria, implying that implicit in this wording is the assumption that to draw is simply to describe and that as such, it accounts for only lower order skills of recognising and describing.

It is clear there is more scope to consider the way that learning outcomes and level

<sup>9</sup> A Levels are awarded by AQA, WJEC (in Wales), CCEA, OCR (run by University of Cambridge), or ISESB (for Independent Schools). Edexcel are the only awarding body to be run by a profit making company, after having been taken over in 2003 by Pearson PLC.

<sup>10</sup> It is unclear what exactly is meant by descriptors like 'independence', 'innovation', 'individuality' or 'in-depth', at this level of learning.

descriptors are expressed for drawing. There is also room to review the role and nature of observational drawing, both within art and design practice and more generally as part of a set of transferable skills.

### **Observational drawing and assessing cognitive skills**

Many point to purposes of drawing beyond making a representation, but what wider abilities can we reliably attach to observational skill, and how should this affect the way we conceive and assess student's drawings? Which of the cognitive skills described by QAA can be developed through observational practice?

In personal communications practitioners responded to the questions: 'What end does this practice serve?' 'What abilities does it enable?' *Observational* drawing practice was said to enable: "decision making, clarity of vision" (Duff, 2010), "[Ability] to analyse visual information through visual rather than textual means, Visual analytical thinking in short, being able to synthesise data visually" (Rohr, 2010) and "The ability to communicate ideas visually, directly through drawing and indirectly through transference of skills learned through drawing to other forms of visual expression" (Hare, 2010).

Many have likewise described observational drawing as a means of visual thinking and analytical learning. David Haley maintains "that drawing is integral to perception and cognitive understanding" (2010). Hudson renamed the activity of observation as 'Construction', describing:

"a piece by piece assembling of awareness, [which] was precisely the way in which children learned by trial, error, and the storing of resulting experience. He saw it therefore as the catalyst of creative education – pre-existing, assisting other matters"

(Thistlewood 1981: 24)

What is common from these opinions is that the range of cognitive skills associated with observational drawing include not only lower order cognitive skills, but the full range of educational objectives in the cognitive domain (Bloom 1956): ‘observation’, ‘communication’, ‘transference of skills’, ‘speculation’ and ‘visual analysis’, ‘decision making’, ‘editorial skills’, ‘synthesis’ and ‘solution’.

A drawing might be assessed, therefore, in terms of the cognitive sophistication with which it was made, rather than its representational accuracy, conformity to ‘convention’ or even its contribution to a further purpose, such as gathering visual information for a design project (this could be a learning outcome better suited to a design brief). Furthermore, I propose that traces of this activity can be visible in the drawing itself and assessment need not rely on extensive annotation to as evidence<sup>11</sup>. Table 1 suggests ways in which cognitive skills might be recognised in an observed drawing.

We might find evidence of close observation and understanding in a drawing’s “correctness, alongside empathy with the subject, and depiction of it in a personally engaged manner<sup>12</sup>” (Duff 2010, personal correspondence). Evidence of ‘application’ might be seen in the employment of analytical visual knowledge, for example, the use of

symmetrical trace lines to balance a figure drawing, or the use of anatomical or structural knowledge to proportion or construct a figure, building or machine. ‘Analysis’ can be seen by the activity of questioning what is seen – marks which refer to not only the visible but to structural or relational properties can provide evidence of analytical thinking. Likewise, there might be evidence that a student has considered the distinction between what they know and what they see in their correction of ‘mistakes’ or acknowledgement of subjective distortions. ‘Evaluation’ will be evident in traces of re-working, changes in composition or measurement. The synthesis of visual knowledge would allow sophisticated decision making, which might be evidenced by a novel choice of line to describe a form or texture, or by an informed, perhaps unconventional, compositional decision<sup>13</sup>. It is perhaps the ‘creativity’ invested in the drawing which gives rise to the ‘wow factor’<sup>14</sup>.

In this way, the range of cognitive objectives can be evident in a single observed drawing<sup>15</sup>. A student’s engagement with this drawing process can be made more explicit, and sufficiently sophisticated objectives and descriptors can be devised without the necessity for additional tasks to satisfy a full range of level descriptors<sup>16</sup>.

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<sup>11</sup> Annotation can be useful for reflection when appropriate, but it evidences a student’s ability to verbalise and post-rationalise their learning, rather than the learning itself, and therefore is not a reliable form of evidence for assessment.

<sup>12</sup> Leo Duff describes this as the main criteria with which she assesses the quality of students’ observed drawings, communicating this both in writing and in one-to-one and group discussions (personal communication).

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<sup>13</sup> These are intended only as examples. There are surely as many ways of identifying cognitive skills in a drawing as there are in a piece of writing.

<sup>14</sup> See Gordon (2004) for a discussion of the ‘wow factor’ in art & design assessment.

<sup>15</sup> Affective and psychomotor domains of skill can also be regarded as important for observational drawing. Space does not permit a full discussion of this here, but comments about how these considerations might be included in curriculum design and assessment are also welcome.

<sup>16</sup> Howard Riley’s ‘matrix of systems of choices’ (2008) is also useful in defining and communicating learning objectives, it plots levels of engagement against functions of drawing.

Higher order cognitive skills ↑	<b>Cognitive skill</b>	<b>Corresponding drawing activity</b>
	<b>Creation</b>	Conceiving of novel ways of approaching the task, subverting existing drawing conventions, exploiting drawing as a means to addressing an identified issue.
	<b>Evaluation</b>	Reviewing the success of marks made, the extent to which a drawing conveys a sense of its subject in the desired manner.
	<b>Synthesis</b>	Making compositional or other decisions, conceiving of the drawing as a whole, considering denoted or connoted meaning in relation to surface features, compositional planning, constructive and mark making strategies towards a particular aim.
	<b>Analysis</b>	Seeking a particular type of feature, examining relationships (e.g. between tonal, textural or linear differences) and determining arrangement, identifying components in relation to the whole, comparing what is seen to what is known, comparing what is seen with what has been drawn, questioning assumptions about the way things look.
	<b>Application</b>	Compositional choices, employing strategies of constructing images, finding appropriate mark making to describe something in a particular way, using analytical visual knowledge.
	<b>Comprehension</b>	Discerning, translating/interpreting percepts into drawn marks, distinguishing relationships.
	<b>Knowledge</b>	Looking, observing, noticing features & picture primitives, describing/communicating visually.

Table 1. Drawing activities corresponding to Bloom’s (1956) taxonomy of educational objectives.

**Transferable skills**

If cognitive skills are employed in observational drawing, can we assume that observational skill acquisition leads to any collateral, transferable benefits? Any causal relation would be hard to measure as any enhancement of overall graphicacy or visual cognitive ability will most likely be the result of combined activities.

Seely & Kozbelt use psychometric testing<sup>17</sup> to demonstrate a relationship

between perception and cognition in their recent research into ‘artists’<sup>18</sup> perceptual advantages’. They provide evidence that perceptual skills confer “an advantage in visual analysis” enabling ‘attentional strategies’ that “enhance the perceptual encoding of stimulus features diagnostic for the identity of objects and inhibit the perception of potential distractors” (2008: 153). This is, perhaps, another way observational skills can be considered in relation to graphicacy.

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an image, they are also better judges, more sensitive to the skill employed in the construction of an image, suggesting necessarily tacit elements to assessing visual skills.

<sup>18</sup> They refer specifically to artists who have representational drawing or painting skill.

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<sup>17</sup> Although their most recent work (Kozbelt et. al. 2010) relies on artists to assess the success of image making tasks, and shows that artists are not only better at constructing

QAA (2008) list transferable skills associated with art and design, but what is implied above is that the abilities enabled by drawing are even more fundamental and have to do with one's ability to concentrate, to attend, to consider, to observe, to comprehend. If practiced regularly, visual cognition can become embedded in ones thinking, in much the same way that a habitual practice of writing would establish the propensity to analyse the world linguistically<sup>19</sup>.

Two further senses in which observational drawing skills might be considered broadly transferable are suggested below. The first considers embodied cognitive perspectives on the relationship between perception and cognition. The second considers notions of analogical transfer and suggests ways of considering transferable skill in teaching practice.

### **Embodied cognition and drawing**

Drawing is widely thought to sharpen sensori-motor awareness and expand visual memory by virtue of time spent paying close attention to the visual world. A more intimate knowledge of the way the world looks, and is physically structured, is valuable in itself, particularly to artists and designers. However, it can be considered more widely valuable when contemporary embodied-cognitive perspectives are taken into account, as these perspectives illustrate the relationship between perception and cognition.

Developmental cognitive neuro-psychologists now widely acknowledge

that sensory understanding and cognitive thought are inseparable, in that they develop in tandem and make use of the same neural pathways. For example, Usha Goswami describes how our "knowledge representation is rooted in attention to the perceptual structure of objects and events" (2008: 51). He also describes how the foundation of our cognitive framework for exploring and representing the behaviour of objects is shared with that of the behaviour of people:

"the attribution of belief and desires seems to develop from the same sources as the attribution of causal mechanisms such as collision and support – namely from the perceptual (mental) representations of the dynamic spatial and temporal behaviour of objects and agents" (Goswami 2008: 46).

He goes on to relate sensitivity to space, objects and causal relations to more abstract cognition such as conceptual representation, memory, logic, and a sense of agency. Empirical evidence supporting these claims lies in the shared neural loci of experience for concepts and percepts.

Cognitive linguist Mark Johnson builds on this paradigm, explaining that embodied understanding is the foundation for thought: "meaning and thought emerge from our capacities for perception, object manipulation, and bodily movement" (2007: 113 see also Johnson 1990). This is the basis of metaphor. The neural 'body in the mind' reconstructs tactile, spatial and visual experiences to make sense of more abstract ideas. Hence it makes perfect sense for an idea to be thought of as having tactile or spatial qualities; being slippery, fragile, liquid, heavy, difficult to grasp, thrown or bounced around. They can be held lightly,

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<sup>19</sup> Other examples of this view include Petherbridge (2008), Riley (2008), Corte-Real (2009), IDEAL Project (2009), Haley (2010), Kantrowitz (in press).

built up and then shattered, attacked and defended<sup>20</sup>.

The proposition this logic allows is that time taken to conduct observed drawing has the ability to enrich cognition in a holistic way. This is, perhaps, another way observational drawing might be included in contemporary notions of graphicacy.

The implication here is that time spent drawing is valuable by virtue of the intensity of experience the drawer has, which will contribute to their cognitive capacities and to any design or visual artistic practices. This is by no means a new idea. Nicolaidis insisted that “the effort you make is not for one particular drawing, but for the experience you are having” (1990 [1941]: 2).

This holistic aspect of learning is primarily concerned not with the ‘quality’ of the drawing, but of the drawers’ experience. This is, again, something hard or even impossible to measure. Yet the quality of the experience of drawing process is something most drawing tutors trust in, despite the fact that it cannot be expressed in writing as a measurable outcome.

### **Observational drawing & analogical transfer**

Tormey suggests a need to move away from teaching drawing simply as a means to creating ‘conventional’ images,

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<sup>20</sup> Despite the ubiquity of metaphor, it is not so acceptable for it to be used in learning outcomes and assessment criteria. Richard Hamilton believed the learning process to be analogous to that of organic growth (Thistlewood 1981), but this metaphor would seem out of place in a module specification, and might only be used after the fact to explain the meaning of more obtusely worded descriptors or objectives to puzzled students.

towards a teaching that ‘facilitates cognitive understanding’. She notes that “in the past, technical skill for representational purposes may have been separated from cognitive understanding, but less so now” (1997). Similarly, Bruce Archer identifies a need for drawing ‘as a training in thinking’ to be taught in addition to drawing for the purposes of representation (1997). What might drawing ‘as a training in thinking’ involve? Here I will suggest that drawing can be also used as a basis for analogical reasoning and learning.

Laura Novick (1988) describes surface and deep levels of analogical reasoning. She explains how a novice is able to apply surface features of an experience in analogical reasoning, while an expert can relate superficially unrelated tasks by structural comparison. In this way learned problem solving strategies can be transferred across disciplinary and thematic boundaries.

Daugherty & Mentzer (2008) review research into analogical reasoning and its significance for engineering design students. Emphasising its importance for creativity, they describe the way that analogies aid in the development of knowledge. They state that this takes place by the application of structural logic from a ‘base domain’ to a ‘target domain’. This can be enhanced by “[r]epresenting either or both the base or target domain to improve the analogy [to] further establish conceptual change”.

Gentner & Jeziorski (1993) note that while tutors often use analogy to explain concepts to students, “analogical reasoning is rarely formally taught”. Drawing can be thought of as useful in this way. It can serve as a base domain from which to source creative and learning experiences. As established above, observational drawing activity encompasses cognitive activity in a relatively

straightforward and visible way. Drawing process can also be considered analogous to *creative process* in a number of ways:

- Both begin from a single point, be it given or chosen.
- Both involve cycles of construction and destruction.
- Focus must shift between smaller elements and the whole to maintain coherence (stepping back and leaning in during making).
- Both involve aesthetic decisions and compositional planning.
- A range of strategies can be chosen, e.g. beginning from a specific point and working outwards, or working from the general into the specific.
- It might be necessary at some point to erase large portions and re-draft. For example, if an error is found, if a preferable compositional choice is found (highlighting the need for ongoing evaluation), or if the purpose (or subject) of the drawing changes.

Strategies for constructing a coherent whole can be tried and tested, and progress over time is clearly visible, both within and between drawings. These qualities render drawing a valuable resource for reflection on learning and for approaching analogous processes. It can be seen as a broad base for analogical reasoning. Acknowledgement of, and reflection on, this structural similarity can serve as a valuable opportunity to consider analogical reasoning. Relatively simple drawing experiences can be used as opportunities for considering more

complex creative or cognitive problems in other domains. A tutor might refer to strategies for constructing a drawing, for example, when discussing approaches to constructing a written argument, to the design process, or to perseverance in learning more generally. Students might also be encouraged to use drawing as a base domain in analogical problem solving for design.

Again, this is a form of learning that cannot easily be measured. Transferable skills are, by nature, flexible, rhizomatic, unpredictable. To apply the logic of one discipline to an analogous novel situation requires both flexibility of thinking and a repertoire of problem solving experiences. What analogous experience a student may have used in solving a design problem, or approaching an essay, might never be known. It could be that by encouraging a student to consider analogical reasoning based on an understanding of drawing, they are inclined to a better understanding of analogical reasoning itself, and as a result solve a novel problem by applying existing knowledge. This would be highly individual for each student, relating to their own unique experiences and challenges. Impact of this kind would be neither entirely predictable nor measurable. It might even go wholly unnoticed, but it would be of lasting importance to the student.

Both of these examples relate to holistic approaches to teaching and assessment that account for non-verbal learning and individual differences. I suggest that it is possible to consider observational drawing as part of an expanded definition of graphicacy, which accounts for the capacity drawing experiences have to enable visual cognitive abilities and creative problem solving, and to facilitate abstract conceptual thought through an enriched visual knowledge of the world.

## Conclusion

Tacit, non-verbal and difficult to measure knowledge is recognised as important but often cannot be made explicit. To acknowledge this is not fall short of our obligation to the QAA, but to hold the same rigour of accountability to the mechanisms that audit our degrees. To accept tacit and holistic learning outcomes, we would need to expand the rationalist box of practices that are legitimated by the QAA, Edexcel and other professional bodies, to be more flexible and to include subtler, more holistic and tacit aspects of observational drawing and similar skills.

At the same time I propose that it is possible to work within these frameworks to consider how learning outcomes for drawing might be better expressed to include notions of transferable skill. I propose that the range of cognitive learning represented by Bloom's taxonomy can be found within the act of observational drawing. Likewise, the

creative process is also analogous to the practice. These facets render it a potentially broadly valuable source for analogical transfer and reasoning. Furthermore, embodied cognitive perspectives have the ability to shift concepts of the value and purpose of observational drawing towards a more holistic view of transferable skills.

I am not suggesting that we privilege transferable skills over more immediate applications of drawing, or that 'tacit' skill be valued over propositional knowledge. Only that it is conceivable that we can openly acknowledge this type of learning within rational educational frameworks, both in teaching and assessment practices. In doing so we can enable an expanded definition of drawing with potentially extensive benefits. It is possible to consider more explicitly the way learning outcomes for drawing are worded, but it is also necessary to acknowledge that sometimes this is not possible and that should not marginalise less measurable learning or holistic approaches to curriculum development.

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## Examining sketching ability within initial technology teacher education

*Diarmaid Lane, Niall Seery and Seamus Gordon*

### Abstract

*Literature concerning freehand sketching (Verstijnen, 1998, Fish, 2004) claims that there is a lack of empirically validated models of instruction which promote the development of freehand sketching as a sense-making, reflexive, problem solving tool.*

*This paper presents an aspect of a larger research study (Lane, 2011) which was carried out within Initial Technology Teacher Education (ITTE) to examine how sketching expertise could be developed in undergraduate students. Using a pre and post test design, the study applied a model of sketching activities which ranged along a continuum from observation to imagination. The effectiveness of the model was empirically examined using various methods. The paper describes the application of visual and verbal protocols (Middleton, 2008) to examine improvement in students sketching behaviour and their ability to externally support complex cognitive modelling episodes through the medium of freehand sketching.*

*The methodology describes how sketching skill, behaviour and cognition can be examined prior and subsequent to participating in specially designed sketching development activities. The novel adaption of Middleton's (2008) visual*

*and verbal protocols scheme enables comparisons to be made with expert sketchers as well as individual student's performances at pre and post-instruction.*

*As the complex behaviour and cognition associated with freehand sketching is tacit and implicit in nature, this paper should be of interest to educationalists and researchers who wish to understand how development in sketching expertise can be examined.*

### Introduction

Freehand sketching is a complex, tacit and implicit skill which supports the retrieval, manipulation and synthesis of visual mental imagery. The development of sketching expertise in students of technology education is necessary, as it helps to support reflexive geometric problem solving in addition to acting as a sense making tool for solving design based technological problems. Verstijnen et al. (1998) claims that there is a lack of empirically validated models of instruction which promote freehand sketching skill, and this is also supported by Fish (2004) who states that there is an insufficient amount of literature which describes how freehand sketching supports the "visualising instinct".

This paper describes a method for empirically examining the development of sketching skill in undergraduate students within Initial Technology Teacher Education (ITTE) as a result of participating in a specially designed model of instruction (Lane et al., 2010, Lane, 2011). Prior to considering the design of the method, a review of the literature concerning the importance of freehand sketching and various methods of examining expertise is presented.

### Freehand sketching

Fundamental to creative expression and designing, sketching offers a medium to problem solve, record ideas for later use and to explore design modifications and alternatives (Prats, 2009). It is a low cost, fast and flexible tool (Prats, 2009) that allows people such as designers, problem solvers and geometers to generate external representations or early sketches that can be utilised as a medium in reflexive conversation between the sketcher and the brief (Kim, 2009) as a “*sense making activity*” (Kimbrell, 2004).

Sketching is the ability to produce a snapshot image of cognitive activities (Schutze, 2003) during the development of visual, creative ideas and hypotheses (Fish, 1990, Suwa, 1998a). Initial sketches or “*study sketches*” are completed in the early stages of design activities and are of particular interest in design and technology education. Freehand sketching promotes innovation and creativity in design based activities as well as tasks which require geometric problems to be solved. These result in sketches being generated which are sometimes so idiosyncratic that they are only comprehensible by their maker (Goldschmidt, 1991).

The demand for sketching is stimulated by the need to foresee the results of

manipulation and synthesis of objects without actually seeing or executing such operations (Fish, 1990). The utilisation of scaffolds such as words, pictures and models as imitations of objects, scenes or events not physically present, significantly increases the ability to engage in mental visualisation (Fish, 1990). The retrieval, manipulation and synthesis of visual mental imagery are critical during sketching episodes especially when:

- Comparing distances among objects not physically present
- Comparing angles between and orientation of objects when viewed from different angles
- Verifying that a new object lies along a particular direction in relation to previously observed objects
- Developing the skill of mentally anticipating the consequences of visual movement. (Finke, 1986)

The pedagogical challenge within Initial Technology Teacher Education (ITTE) is to develop undergraduate students' sketching ability along a continuum which ranges from observation to imagination, figure 1. Students need to develop fundamental observational drawing skills where they can build graphical libraries from perceived visual information and communicate these in a slow, controlled and reflective manner. The progression of this complex cognitive skill towards imagination results in students' behaviour becoming automatic and reflexive in nature. Sketching becomes a “*sense-making*” (Jonson, 2005) activity where libraries of visual mental images are retrieved, manipulated and synthesised into conceptual externalisations. Libraries of visual mental images are retrieved, manipulated and synthesised into conceptual externalisations

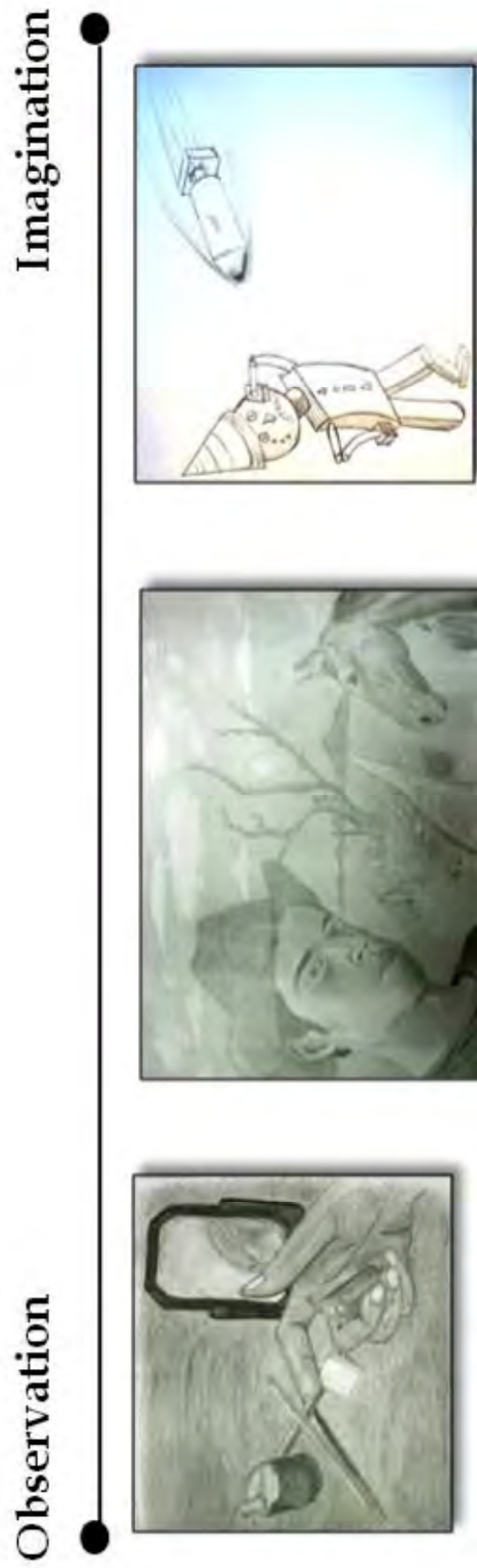


Figure 1. Continuum of development for freehand sketching skill

The next section of the literature review considers how sketching skill can be empirically examined.

### **Examining sketching expertise**

Verstijnen et al. (1998) argues that many of the techniques presented within the literature relating to the development of freehand sketching ability are novel but the effectiveness of these is largely subjective and anecdotal in nature and as a result it may be subject to debate.

Recent research (Lane et al., 2010, Lane, 2011), examined the effectiveness of a specially devised model of sketching activities in developing sketching expertise in undergraduate students of Initial Technology Teacher Education (ITTE). Considering the tacit and implicit nature of sketching behaviour and cognition, it was difficult to identify an independent valid and reliable test capable of measuring any improvement in sketching skill.

Literature concerning expertise in freehand sketching identifies some suitable methods for measuring sketching skill, behaviour and cognition. These include criterion referenced assessment (Yang, 2007, Goldschmidt & Smolkov, 2006), cognitive tests (Finke, 1990) and visual and verbal protocol analysis (Middleton, 2008). The design of these tests was considered in terms of their appropriateness for assessing pre and post-instruction sketching ability of students.

Due to the complex nature of the research study, this paper is only concerned with describing the application of visual and verbal protocols to examine the development of sketching expertise. Literature concerning the application of visual and verbal protocols is described in the next section.

### **Protocol analysis**

Visual and verbal protocols provides a rich source of data in relation to how people deploy a range of cognitive procedures and behaviours during specific tasks (Middleton, 2008). Notable research methodologies which use visual and verbal protocol analysis during design based sketching activities have been described by both Suwa et al. (1998b) and Middleton (2008).

Suwa et al. (1998b) provides a detailed scheme to code the cognitive actions of designers during visual and verbal protocols where four major categories correspond to different levels of cognitive processing. Each major category is in turn broken down into subcategories with relations between actions such as dependencies and trigger relations. Subsequent to examining the scheme designed by Suwa et al. (1998b), it was considered too complex to delineate and there appeared to be limitations within the scheme in relation to conceptual type actions (Suwa, 1998b). As freehand sketching is a sense-making tool which supports the synthesis of visual mental imagery, it is important that any scheme for visual and verbal protocols supports conceptual type actions.

On the other hand, Middleton (2008) provides a detailed description of the application of visual and verbal protocol analysis to examine cognitive actions among design students and architecture students during sketching based design tasks. Cognitive actions from the visual and verbal protocols were broken down into ten types of procedures which were then located between three major categories which included; Exploration, Generation and Executive Control (Middleton, 2008).

Samples of the type of data which can be outputted using this scheme are shown in Figure 2 and Figure 3. Note the very

different types of strategies applied; where Figure 2 illustrates the cognitive actions for a competent sketcher and Figure 3

illustrates those of an expert sketcher. The expert engaged in significant exploration at the beginning and the brief was largely resolved by tentile 4.

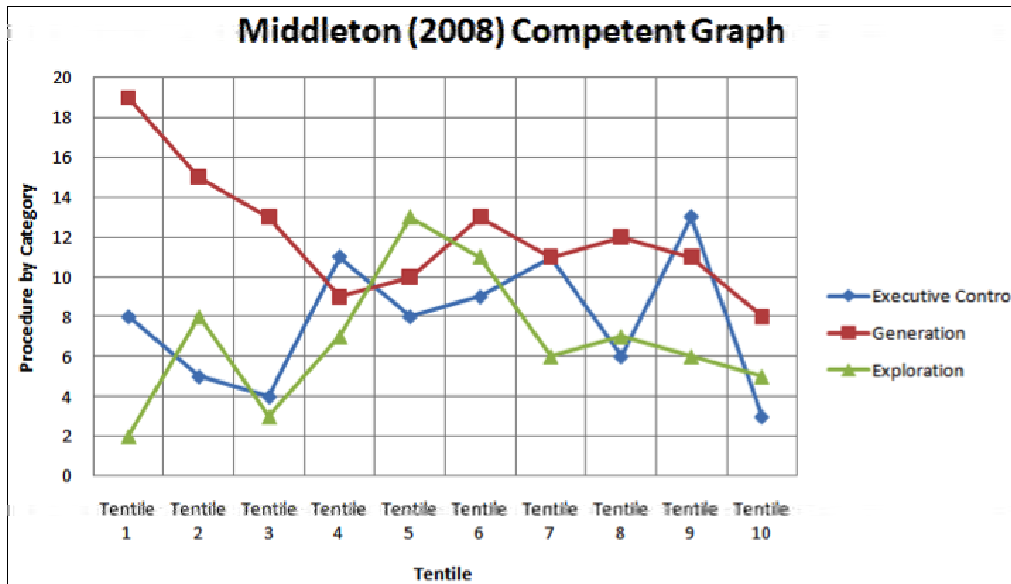


Figure 2. Plot showing cognitive procedure of a competent designer during a design based sketching task (Middleton, 2008)

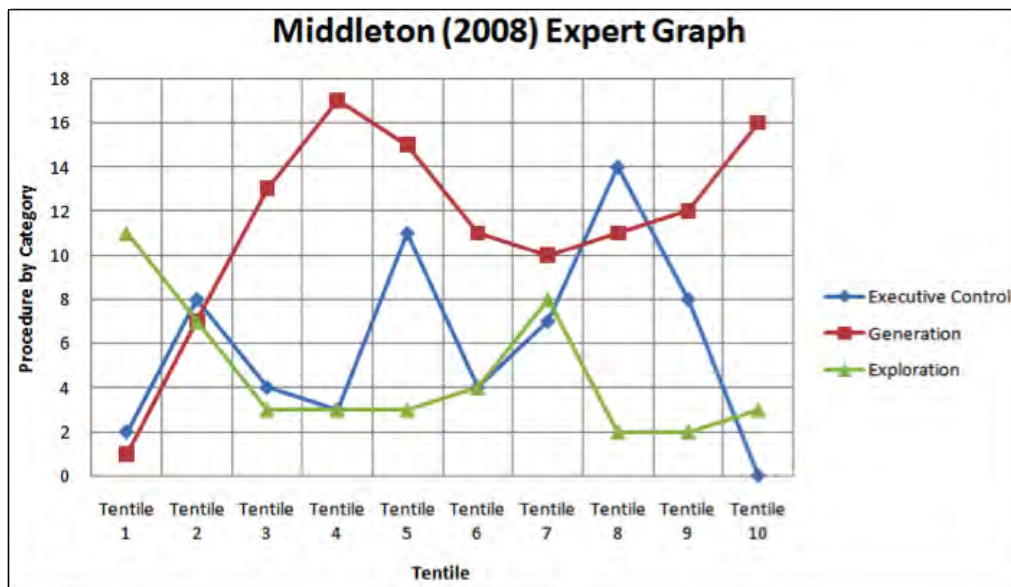


Figure 3. Plot showing cognitive procedures of a competent designer during a design based sketching task (Middleton, 2008)



Reliability was addressed by Middleton (2008) by providing a detailed description of the research setting, participants and the methodology applied. Considering the simplified breakdown of cognitive procedures and the detailed methodology described by Middleton (2008), it was felt that this scheme would provide a necessary model for examining the pre and post-instruction sketching ability of students within ITTE.

### **Design of the research study**

Based on the literature it was decided that the effectiveness of Lane's model of sketching activities (Lane et al., 2010, Lane, 2011) would be examined using a pre and post-test (Cohen et al., 2007) approach. Due to the tacit and implicit nature of sketching skill, three methods were identified to measure the development of sketching expertise. Firstly, a "*Conceptual Sketching Exercise*" was applied to examine students' ability to synthesise basic geometries to generate a conceptual type character. Secondly, a battery of psychometric tests were applied to determine if there were any underlying cognitive factors which predicate the development of sketching expertise. Finally, visual and verbal protocols were applied to gain a deeper insight into the sketching behaviour and cognition of students while solving design based technological briefs. The application of this visual and verbal protocols method is the focus of the next section.

## **Research method**

### **Overview**

The participants for the visual and verbal protocol element of the research study were all year three undergraduate students of Initial Technology Teacher Education (ITTE). In total, 41 students volunteered to participate. The research was carried out as an element of a Design and Communication Graphics module of study which was undertaken by an entire cohort of 137 students. The focus of the module was to enable students to bring their understanding of geometric concepts and principles on a "*journey*" (Hope, 2008), which explored ill-defined geometric problems within a design driven environment through the medium of freehand sketching. All students undertook a series of specially designed sketching based activities which ranged from observation to imagination (Figure 1) over a four week period.

The protocols were conducted in a classroom similar to that in which graphics and design activity usually occurred within the university and they took place in the evening time outside of normal classroom hours. The students were scheduled to attend in groups of six for a thirty minute period. The research experiment comprised of three main stages (Figure 4). The "*Design of Sketching Based Tasks*" is described in the next section.

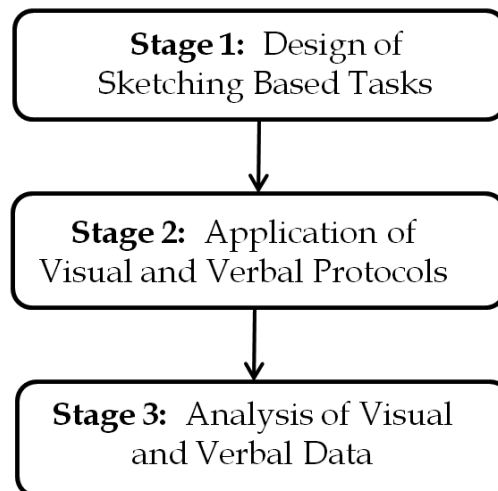


Figure 4. Design of framework

### Design of sketching based tasks

The pre and post-instruction sketching based design problems needed to meet a number of specifications similar to those defined by Middleton (2008). These included the following:

1. It had to be a problem that was related to the student's course of study
2. The problem had to be authentic and of common interest to all students
3. The problem had to contain some features that would make it challenging for all students

Based on the above criteria, it was decided to refer to previous Leaving Certificate "Technology" coursework briefs (S.E.C., 2011, 2009) and design tasks that the students carried out in previous modules (Seery et al., 2010) in order to design appropriate briefs for the visual and verbal protocols. The "Technology" coursework briefs describe a thematic problem which

needs to be solved through the design and production of an artefact. The design of both briefs contained an element relating to personalising the design for a specific purpose. All students were previously given similar criteria in a module reported by Seery et al. (2010). The following two briefs were devised:

1. Pre-Instruction: "Boiling water is an essential task that people carry out in everyday life. You are required to design an artefact for boiling water for a person you hold in high regard. The artefact must have some sort of an electrical or mechanical movement and it should be appealing to the person it is designed for".
2. Post Instruction: "Toys for young children are often attractive, exciting and robust. You are required to design a concept toy for a child that you know. The toy should incorporate mechanical or electrical movement and it should be appealing to the child it is designed for".

### Application of visual and verbal protocols

Each student was given a headset to record verbal “*think aloud*” (Middleton, 2008) actions while a webcam was set up to discretely record the visual sketching actions during the sketching process. A computer screen was positioned in front of the students so that they were aware of what was being recorded (Figure 5). Prior to the commencement of both the pre and post instruction protocols, instruction was given to students on how to “*think aloud*” and the students were also required to trial the equipment.

The students were allocated twenty minutes to complete the activity and were reminded throughout to keep verbalising their thoughts. The twenty minute timeframe was based on the length of similar sketching tasks described by Goldschmidt and Smolkov (2006).

Figure 6 depicts the environment during the design task process. At the end of the twenty minute time period, the students were asked to stop sketching and give a brief thirty seconds of feedback in relation to the activity itself and their experience of visual/verbal protocols.

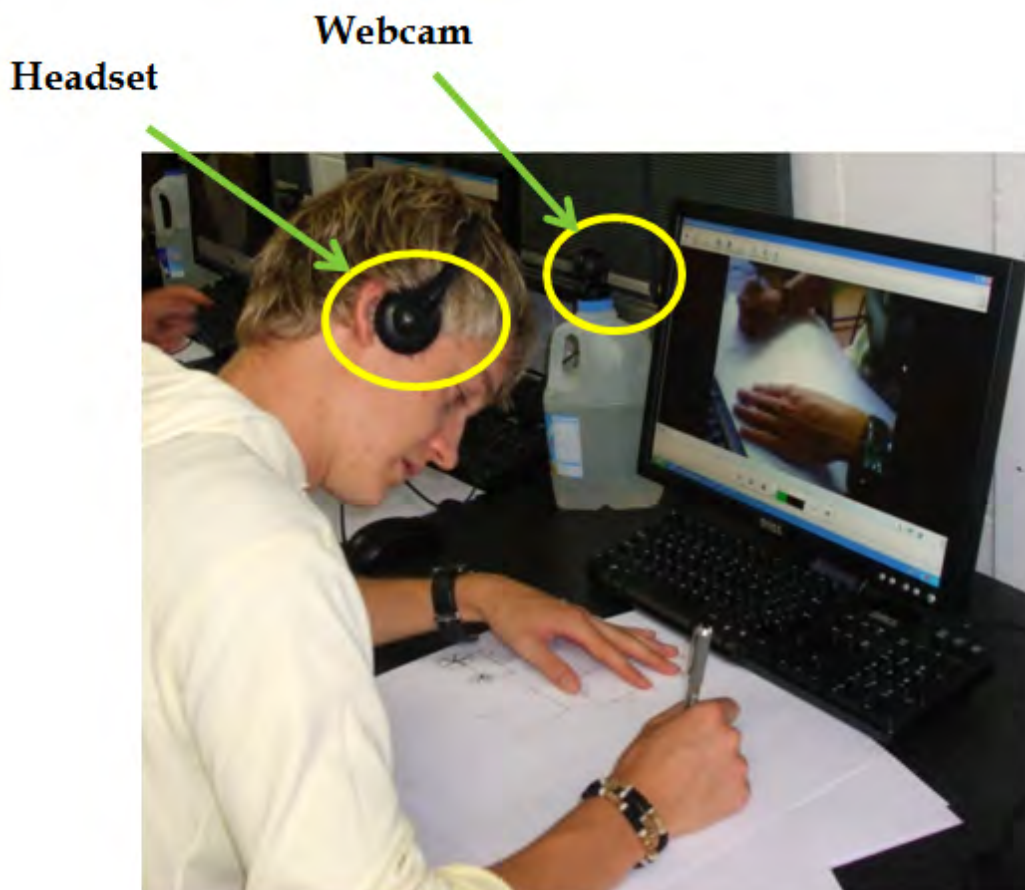


Figure 5. Set up of equipment for visual and verbal protocols



Figure 6. Students sketching during visual/verbal protocols

### **Analysis of visual and verbal data**

Subsequent to collecting the data, all of the videos were examined, the verbal data were inputted and coded and the relationships between the visual and verbal data was analysed.

The continuously recorded video files were transcribed and broken down into segments. The length of the segments was determined based on the smallest unit of meaning that suggested one cognitive action. Cues for segmenting protocols included; pauses, changes of tone as well as the conclusion of sentences (Middleton, 2008).

As the verbal segments were inputted, the visual data were also monitored. This enabled a distinction to be made between sketching episodes and non-sketching episodes. Once all of the verbal data were inputted, Middleton's (2008) categorisation of procedures was utilised to code the cognitive actions of each student. Each cognitive action was coded into one of ten procedures and was then located within one of three major categories of procedures as shown in Table 1.

Category of Procedure	Generation	Exploration	Executive Control
Procedure	Retrieval (R) Synthesis (S) Transformation (T)	Exploring Constraints (EC) Exploring Attributes (EA)	Goal Setting (GSet) Strategy Formulation (SF) Goal Switching (GSwit) Monitoring (M) Evaluation (E)

Table 1. Middleton's categorisation of cognitive procedures

The researcher coded all the segments independently in order to maintain internal reliability throughout the study. Where there was uncertainty surrounding the coding of

some verbal data, the visual data were examined to determine a better insight into the nature of the cognitive action. Examples for each procedure are shown in Table 2.

Procedure	Example
Retrieval (R)	<i>"Dresser here at this side as well... Must be 200 years old if it's a day"</i>
Synthesis (S)	<i>"Am... we can make this big, solid and strong so that it can survive the child playing with it"</i>
Transformation (T)	<i>"So little dimples here to make it known that that has a cushiony feel..."</i>
Exploring Constraints (EC)	<i>"But these could have small niggly bits and could be unsafe to use so..."</i>
Exploring Attributes (EA)	<i>"The first thing comes into my mind would be my godmother's daughter's child and he is 3 years of age..."</i>
Goal Setting (GSet)	<i>"I want to make a device for boiling water for my father which will incorporate hurling into the design"</i>
Strategy Formulation (SF)	<i>"So I'm going to start off by just drawing a simple hurl"</i>
Goal Switching (GSwit)	<i>"So next we could maybe design a window..."</i>
Monitoring (M)	<i>"As the dog is just a small terrier the height doesn't need to be that big..."</i>
Evaluation (M)	<i>"I'm sure there are more features that could be added"</i>

Table 2. Examples for procedures of cognitive actions

Within visual and verbal protocol analysis it is important to divide the data into a number of parts to allow for in-depth analysis. Some researchers such as Suwa et al. (1998b), resort to breaking the segments down according to the number of pages of sketches produced. In contrast, Middleton (2008) cites the importance of pauses and changes in the rate of problem solving during sketching based design activities and they base the division of the verbal data on the duration of the entire sketching episode. This approach by Middleton (2008) was adapted in this study, where the entire twenty minute duration was broken down into ten, two minute tentiles<sup>21</sup>.

When all the pre and post instruction data were broken into tentiles, it enabled the creation of three plots for each student. These illustrated the number of cognitive actions for each category of procedure at pre and post-instruction in addition to those of Middleton's (2008) expert. An example is provided in Figure 7 where the cognitive actions at pre and post-instruction are compared to each other in addition to Middleton's (2008) expert. This was a novel adaptation of Middleton's scheme as it not only enables comparison to be drawn with an expert; it also allows comparisons to be drawn between students' pre and post-instruction sketching behaviour and cognition. The sketches generated by each student at pre and post-instruction were also compared and analysed in order to gain a further insight into students sketching behaviour. All sketching and non-sketching episodes were examined and a timeline was generated for each student at pre and post-instruction. The timeline provides an insight into when the students were sketching and what sketches they were generating. Examples of the type of pre and post-instruction sketches generated by students

and the corresponding timelines are illustrated in figure 8 and figure 9 The following approach (which was informed by the literature) was taken to analyse these sketches.

**1 How many sketches were produced during the pre and post-instruction?** Expertise in freehand sketching is associated with a higher number of cognitive actions during design based tasks (Kavakli et al., 1999).

**2. How sophisticated and creative were the sketches that were produced? How much detail was communicated in the sketches?** Sketching expertise is comprised of two components. These are fluency and a command of the orthogonal projection system (Goldschmidt, 2003). Expert sketchers tend to communicate significantly more detail in their sketches (Kavakli et al., 1999) (Yang, 2007).

**Was there evidence of exploration and synthesis of ideas?** Expertise in freehand sketching is associated with high levels of creativity (Verstijnen, 1998). Experts tend to engage in significant exploration at the beginning of design based sketching tasks while the rate of generating actions tends to increase as the activity progresses (Middleton, 2008) (Figure 3). Expert sketchers tend to perform better in "restructuring" tasks (Verstijnen, 1998). Evidence of association between spatial features and meaning within sketches tends to be higher in expert sketchers (Kavakli et al., 1999).

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<sup>21</sup> A tentile represented one tenth of the entire length of the sketching episode.



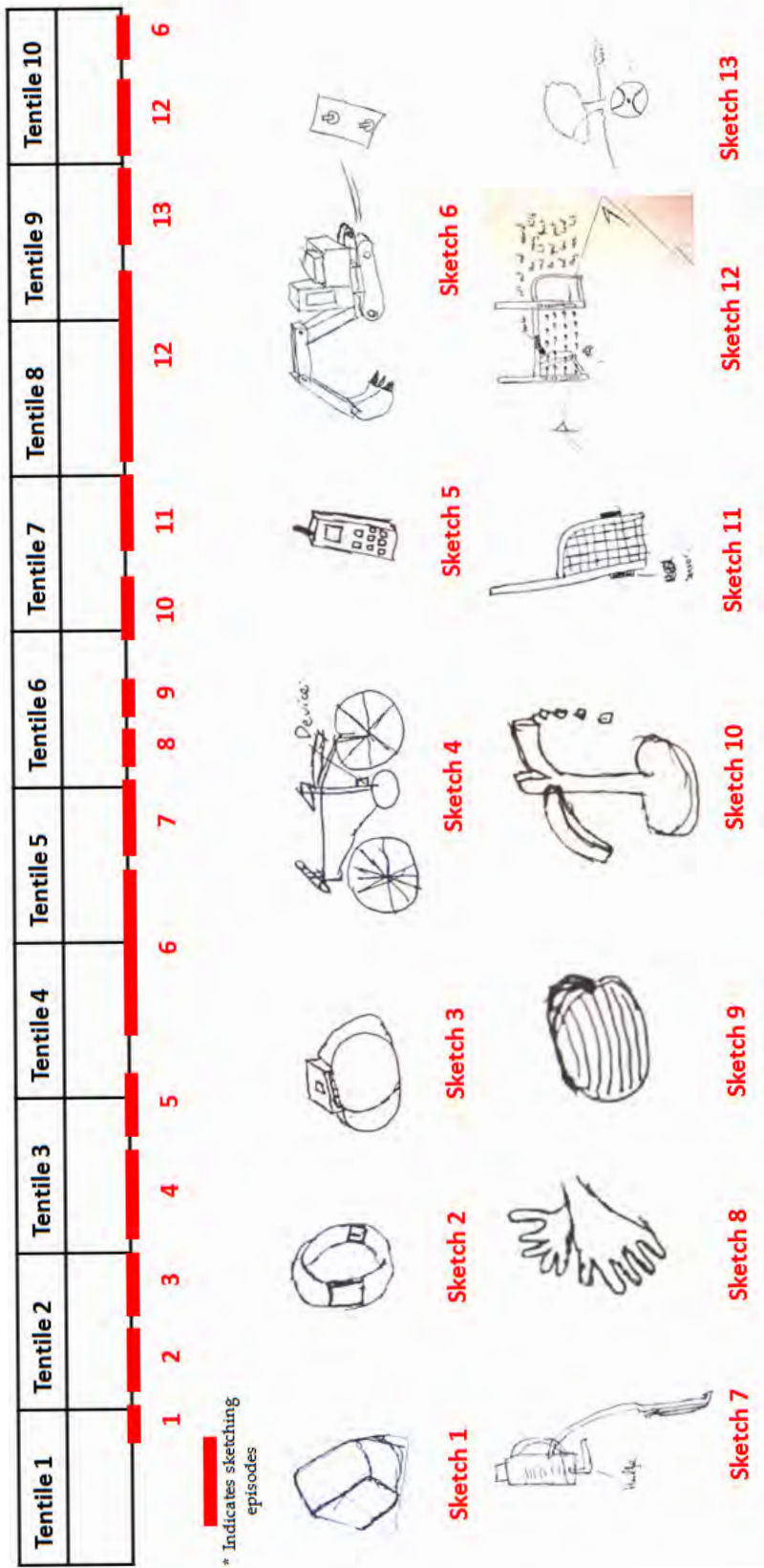


Figure 9. Post instruction visual and verbal protocols sketches and time line for student 96



Finally, further analysis of the verbal data was necessary in order to further understand students' levels of motivation and the difficulties they encounter during sketching episodes. This is especially important when examining the development of sketching expertise in order to validate models of instruction. Verbal actions which could provide a further insight into students' sketching behaviour include the following:

1. How motivated are the students as they solve the problem?
2. Are the students critical of their performance?
3. Do the students look for visual stimuli to support the problem solving process?
4. How long does it take the students to solve the problem?
5. Do the students explore alternative solutions?
6. Do the students refer to previous learning experiences?

The next section considers the value of the research method presented in this paper and the implications it has for examining sketching expertise within design and technology education.

### **Implications for research methods**

The novel adaption of Middleton's (2008) scheme for visual and verbal protocols in the current research has significant implications for educationalists and researchers within design and technology education who are interested in examining sketching expertise in students. The method not only allows comparisons to be made with experts (Middleton, 2008), it also enables comparisons to be made for individual students based on their performance prior and subsequent to participating in specially designed sketching development activities.

The rich data which are gathered can be analysed in various ways to capture the tacit and implicit nature of sketching behaviour and cognition. The generated plots (figure 7) allow the researcher to understand the type of cognitive actions of the student as they generate solutions for concept based technological problems. The plots clearly illustrate the amount of cognitive actions evidenced for each ten minute and whether the actions were increasing, decreasing or constant throughout the entire twenty minute episode. It is also possible to compare the students pre and post-instruction cognitive actions to those of a perceived expert (Middleton, 2008).

Analysis of the students generated sketches and the corresponding timelines (Figure 8 and Figure 9) provides a further insight into the complex nature of sketching skill and behaviour of each student. It is possible to compare the type and number of sketches produced by each student at pre and post-instruction while at the same time understanding when each sketch was generated, how long it took to complete and whether it was revisited again during the twenty minute period. In addition to this, it is possible to refer back to the plots of cognitive actions (Figure 7) and relate these to the external representations and corresponding timelines.

It is also important to value the richness of the verbal data recorded during each sketching episode. Further analysis of these data (beyond codifying them in to cognitive procedures) provides a deeper insight into students' sketching behaviour. It is possible to infer levels of motivation, whether students were experiencing difficulties or not and whether their previous learning experiences were impacting on their performance. For example, analysis of one student during the research study presented in this paper revealed that he believed his sketching was very bad and that he "*did not*

*have it in the hands*” because that was what a previous teacher of his had told him. These types of comments are very important in understanding students sketching performance on an affective level.

In describing what was carried out in the research it is worth adding a brief note about what was not done. Firstly, the research did not examine the type of actions which precede or follow sketching episodes. Although these data were gathered it was not felt necessary to analyse them as the method provided sufficient evidence to validate the model of sketching activities which were applied. Secondly, the research did not examine the physical hand movements of each student while they were solving the given problems. This was not necessary for the study presented but future studies might consider this in order to further understand how students interact with sketches on a psychomotor level and how this is linked with their cognitive actions. While these approaches were not necessary for the research presented in this paper, they would be worth considering for other researchers who may apply visual and verbal protocols to examine the development of sketching expertise.

## **Conclusion**

The methodology described in this paper was derived from previous research by Middleton (2008) and applied as part of an ongoing study which is examining the development of sketching expertise within technology education (Lane, 2011). The novel adaption of Middleton's (2008) scheme provided a means of comparing individual students sketching behaviour and cognition prior and subsequent to participating in specially designed sketching activities while at the same time comparing their behaviour to that of a perceived expert.

Although the application of visual and verbal protocols was effective in examining the development of sketching expertise, it is important to realise that other measures were also applied. The triangulation of data from different measures is critical in order to provide an insight into the complex nature of sketching behaviour and cognition.

It is widely accepted that research in this area is in an early stage of development – compared with other areas of education. However, as the IDATER conference at the University of Limerick testified, it is a growing area and it is important to understand and embrace the relationships between different areas of graphicacy and modelling in order to promote and support the *“visualising instinct”* (Fish, 2004).

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## Defining the variables that contribute to developing 3D CAD modelling expertise

*Anthony Rynne, William F. Gaughran and Niall Seery*

### **Abstract**

*The increasingly widespread use of 3D parametric CAD has resulted in a diversity of application and an ambiguity surrounding the definition of user competency. Properly used, parametric 3D CAD modelling systems can be an indispensable tool for developing problem solving skills, design and graphic thinking capabilities, while fostering creative and innovative attributes.*

*While on the one hand, 3D CAD systems have become easier to learn and use with the development of context sensitive toolbars and shortcut menus, on the other hand they have become increasingly sophisticated with an ever increasing array of tools for complex modelling and extended design capabilities. This paper further develops research conducted at the University of Limerick (Rynne and Gaughran, 2008) that set out to define a framework for 3D CAD cognition and developing CAD expertise. In particular, this paper explores the relationship between graphical competency and*

*developing strategic CAD knowledge, focusing on the ability of advanced beginners to deconstruct model geometry as the foundation to developing a strategic modelling approach.*

*The findings compare student teachers' performance in a Plane and Solid geometry assessment with their performance in a CAD examination in an attempt to explore this relationship. An analysis of student CAD models presents empirical evidence of the deficiencies that are apparent in transferring graphical knowledge into strategic CAD knowledge. The students demonstrated difficulty in thinking through efficient modelling sequences in an assigned part modelling task even though they were proficient users of the particular CAD system. Graphicacy and its relationship to developing CAD expertise are particularly relevant in Ireland given the recent extensive integration of 3D CAD into the Senior Cycle subject Design and Communication Graphics.*

### Evolution of CAD systems

The impact of CAD functionality has a direct relationship with end user capability and associated application. From its origins in the 1960s, computer aided drafting and design has witnessed a number of significant changes. Technological advancements have dramatically changed the way in which engineers, designers and educators utilise CAD systems, but graphical competence remains a constant prerequisite for their effective use. Initially, the development of the Sketchpad system in 1963 at the Massachusetts Institute of Technology (MIT) marked the beginning of computer graphics and demonstrated that it was possible to create drawings and alter objects interactively on a computer screen. Research for the remainder of that decade was devoted to developing 2D CAD systems to improve the productivity of engineers and drafters, with the development of surface modelling techniques being largely driven by the requirements of the automotive and aerospace industries for the mathematical definition of complex surfaces. CAD system operations were directly linked to engineering and mathematical expertise and experience. The development of more affordable computer hardware and software in the 1970s resulted in 3D solid modelling systems with shaded graphics being developed which marked the beginning of CAD moving from computer-aided drafting to computer-aided design and modelling.

The ACIS and Parasolid CAD engines emerged. These CAD engines incorporated both boundary representation (B-Rep) approaches which used surface definitions to describe the enclosed solid and Constructive Solid Geometry (CSG) approaches that involved building solid models from primitive shapes and Boolean

combinations of these shapes. The release of Pro/ENGINEER in 1987 by Parametric Technology Corporation (PTC) was the first commercially complete parametric feature-based solid modeller. However, all geometry had to be fully defined, model changes were problematic and using it at that time was more like programming than engineering design (Weisberg, 2008).

In the 1990s, mid-range feature-based parametric design systems that ran exclusively on the Windows operating system began to emerge. SolidWorks, based on the Parasolid geometric kernel, was one of these mid-range modellers and was first released in 1995 by SolidWorks Corporation. The emergence of history-based modelling can be considered second generation solid modelling and is still the basis of today's leading 3D CAD systems. Boundary representation technology is the most accurate means of representing 3D geometry and has currently evolved to enable direct geometry manipulation of model surfaces and edges using push and pull techniques. This is the basis of recent developments in direct modelling systems. The principal difference between history-based and history-free (direct) modelling is the presence or absence of a design tree structure with parent/child relationships between features. In response, leading CAD vendors have begun to integrate direct modelling capabilities into the latest releases of their history-based modelling systems. With 3D CAD systems having become decidedly easier to use and learn, the result is a huge diversity of 3D CAD users from professional designers to second level technology students. In 2007, the Irish Department of Education and Science selected the SolidWorks 3D CAD system to facilitate the integration of CAD into the senior cycle subject Design and Communication Graphics (SolidWorks Corp., 2007). This represented a major

paradigm shift in graphical education in Ireland, and a context in which it is important to identify and develop the generic, yet distinctive CAD skillsets that best promote design thinking.

### Learning CAD

The only certainty in the CAD world is that change will be followed by greater change, so the pedagogic focus must therefore be on developing the learners' design thinking and problem solving capabilities through the development and application of their strategic CAD modelling knowledge. What constitutes strategic CAD knowledge will now be examined. Design intent is the term used to describe how a model should be created and how it should behave when it is changed. It is not just about the size and shape of features, but also their relationships and sequencing, dimensioning methods, the use of equations and the overall effective planning of the model.

For many skilled tasks such as 3D computer-aided design (CAD), the task knowledge of the user or learner is often considered to be of two types: declarative knowledge (DK) and procedural knowledge (PK) (Ryle, 1949; Hartman, 2005). The distinction between these different types of knowledge has been noticed in other skilled tasks and has been labelled as the declarative-procedural knowledge distinction (Lang et al., 1991). Declarative knowledge is knowledge of facts (knowing that or knowing what) and procedural knowledge is knowledge of how to do things (knowing how). To design or model an object in a 3D CAD system, as well as having information on the object being designed, the user must have generic knowledge and understanding of what tools and techniques can be used to build a model, and specific knowledge in relation to how to combine sketched and

applied features to create a digital model. In a similar theme, Wiebe (1999) used Shneiderman's (1998) object-action interface (OAI) model along with the engineering design process as a framework for understanding the software elements to part modelling. At a semantic level Wiebe found that there were clear common themes between all the modellers, while at a syntactic level interface details differed markedly between systems. He suggests that the objects and actions of the parametric modelling interface should serve as metaphors for the objects and actions required of the actual task and that the more closely the task and the interface are aligned the more effectively the software can be used.

However, to strategically create a part model, declarative and procedural CAD knowledge are not sufficient. The term strategic knowledge is used in this paper to denote the additional capabilities required to amplify declarative and procedural knowledge. As indicated in Figure 2 these include graphical and visualisation capability and metacognitive processes such as planning, analysing and evaluating which contribute to the ability of the user to create a cognitive model of the task. In principle, the cognitive model generates the 'know why' and tactical awareness that drives and informs strategic CAD knowledge. Metacognition has been defined as knowledge or awareness of cognitive processes and the ability to use self-regulatory mechanisms to control these processes (Eggen and Kauchak, 1997; Gijsselaers, 1996; Sternberg, 1998). Metacognition is necessary to understand how a task was performed (Garner, 1987). Understanding fundamental graphics principles such as orthographic projection and sectional views, coupled with well-developed visualisation and sketching abilities form the cornerstone of cognitive modelling for



CAD (Bertoline, 1999). The process of externalising and illuminating the perceptual imaging that takes place inside the CAD users' head is best enabled through freehand sketching. This is the ideal tool to facilitate the learner in visualising and cognitively deconstructing a part model into its key features for effective and strategic CAD modelling (Barr, 1999; Sorby et al. 1998). 3D CAD enhances design graphics learning in many vital ways including through the creation of high quality digital prototypes, design animation, simulation and analysis and the fostering of design iteration (Hodgson, 2006). A digital prototype enables the learner to make better and quicker design decisions and provides the flexibility to refine and optimise design changes.

An expert user has the knowledge and experience to automatically build part models in an efficient and strategic manner. For all but the simplest of CAD models, novice and advanced beginners should spend time mentally deconstructing and analysing part modelling tasks into their key constituent sketches and features prior to building the parametric solid model in a CAD system. Effective CAD modelling is therefore dependent on the level of strategic knowledge and metacognitive processing the user applies to the task. The process of cognitively deconstructing a part model and reconstructing, sequencing and synthesising its sub-elements into a coherent intelligent digital model parallels very well the concept of 'technicity' as introduced by Doyle (2004). Doyle uses the notion of technicity as the causal explanation not just for innovation and creativity within design and technology education, but as an elucidation for human evolution itself. He defines technicity as being characterised by a creative capacity to deconstruct, reorder and reconstruct nature and objects and to be able to

communicate by drawing. This concept of technicity is at the core of effectively and efficiently creating a digital model in a 3D CAD system.

Just as cognitive scientists have developed a grammar of vision, a set of rules that direct our perception of line, colour, form, depth, and motion so too there is a need to develop a coherent grammar for the cognition required for parametric modelling. The sense of vision has great ability to actively construct every aspect of our visual experience (Hoffman, 2000). Vision is not simply a matter of passive perception; it is an intelligent process of active construction. Similarly creating intelligent parametric models requires thought and careful planning and involves a well-developed 3D mind-set to actively and intelligently deconstruct and reconstruct part and assembly models (Rynne and Gaughran, 2008). Irrespective of whether the modelling start point is the interpretation of engineering drawings, reverse engineering a part or working from conceptual sketches, the process of building a 3D model is one of actively constructing what the user perceives using appropriate 3D CAD modelling strategies. Efficient design modelling is contingent on capturing the correct design intent of the component from the outset through to the completed model.

However, given that the starting point for a model is oftentimes a legacy 2D drawing or a manual sketch, users must possess the necessary visualisation and model deconstruction capabilities to build an efficient model. In addition, as this paper submits, having pictorial views of a model does not guarantee that even capable advanced beginners will be able to mentally deconstruct a model for effective CAD modelling. At all times model geometry must be viewed as a dynamic rather than a static entity that will probably

need to be changed in the future. A recent 3D CAD software vendor study (Aberdeen Group, 2006) estimated that engineers spend an astonishing 60 to 80 per cent of their time making changes to their designs. However, making design changes and reusing existing designs can only be easily achieved if strategic 3D CAD knowledge practices were used in the original designs. To evaluate the developed CAD framework the following study was carried out.

### Assumptions

- Participants having completed 6 core graphics modules it is assumed they:
  - Have good graphical capability including knowledge of projection systems
  - Have good visualisation skills
  - Have good declarative and procedural CAD knowledge (SolidWorks)
  - Can build part models
  - Understand part level design intent

### Intervention

- Participants completed a 12 week module that focused on:
  - Advanced plane and solid geometry
  - CAD modelling techniques including Surface modelling, Hybrid modelling approaches and multi-body techniques

### Hypothesis

- To test the relationship between Graphical capability and strategic CAD knowledge

### Measure

- Comparison between performance in Graphics and CAD assessment
- Analysis of modelling strategy and application of graphical knowledge

Figure 1. Approach flowchart

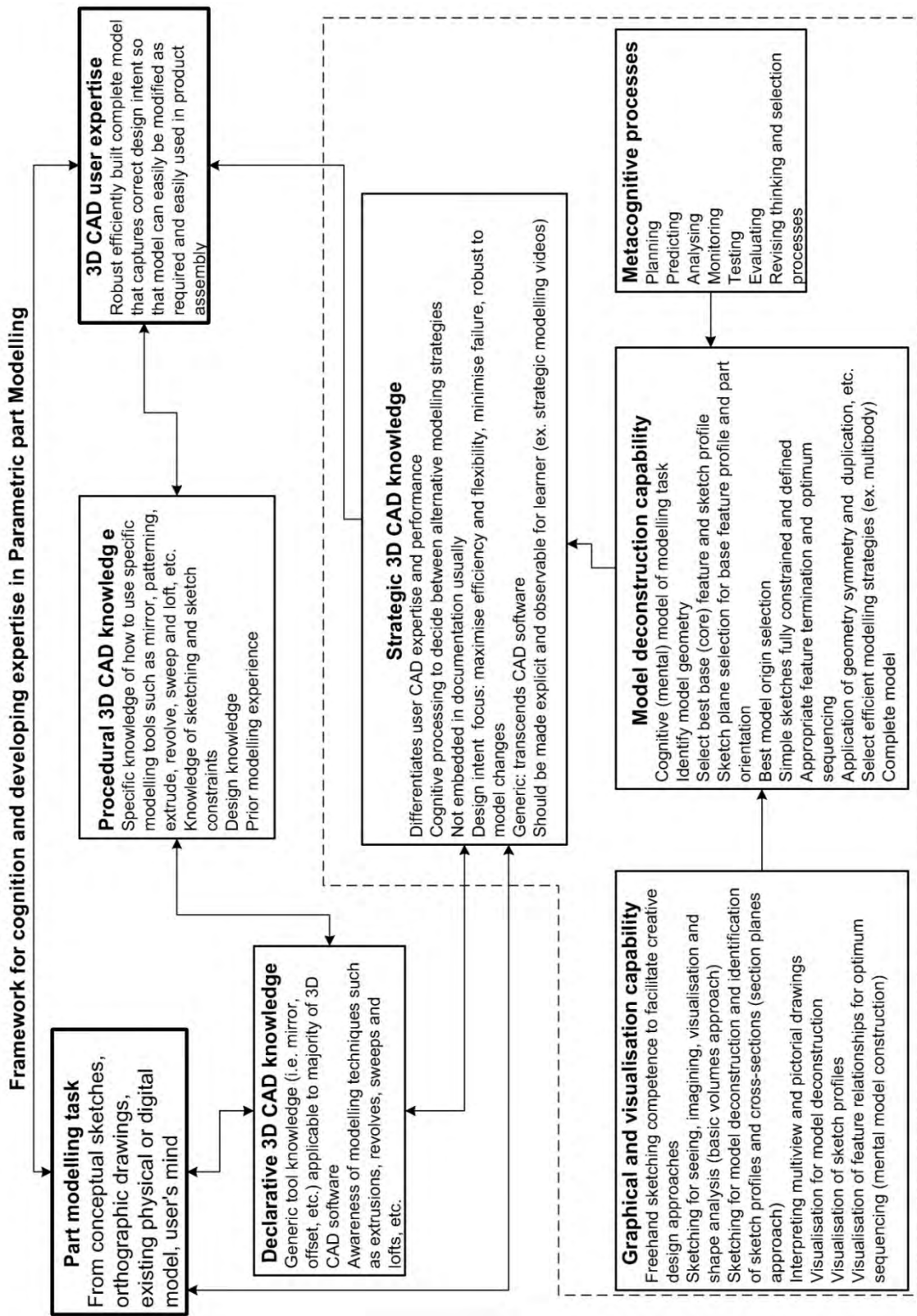


Figure 2. Framework for developing cognition and expertise in 3D part modelling

## Methodology

The approach taken for the research study was to test the graphical and CAD modelling capability of final year pre-service technology education teachers at the University of Limerick following the completion of their concluding graphics module. The concluding graphics module was an integrated engineering design graphics and 3D CAD module and represented the culmination of student learning in these disciplines. Prior to this participants had over the previous three years successfully completed in sequence five pre-requisite graphics modules. Half of one of these modules involved the students in learning how to effectively model using the SolidWorks design software.

During the concluding 12 week graphics module in the final semester the links between geometry and CAD modelling were further explored during which the students completed tasks in advanced plane and descriptive geometry and in CAD modelling using SolidWorks. The hypothesis was that even high achieving learners in design graphics and advanced beginners in 3D CAD use inefficient and non-strategic CAD modelling strategies. The approach taken is outlined in figure 1.

### Participants

1. Fifty three fourth year pre-service technology teachers at the University of Limerick were selected for the study based on the following: Their graphical competency as defined by module performance was representative of the entire cohort (n = 114).
2. These participants are considered high achievers, generally having obtained a B average across 6 honours subjects to gain entry onto the programme.
3. They had previously successfully completed a module on SolidWorks that equipped them to model parts to capture design intent using appropriate combinations of sketched and applied features.

### Design of the method

The design of the method focuses on three distinct areas; the theoretical framework that underpinned the rationale supporting the hypothesis, the modelling activity based on a number of graphical assumptions and the criteria that supported an analysis of the data.

### Theoretical Framework

figure 2 illustrates the principal factors that influence CAD expertise and is a development of the work of Chester (2006, 2007) on the role of metacognition and spatial ability in developing CAD expertise and is a progression of previous CAD research at the University of Limerick (Rynne and Gaughran, 2008). The framework highlights the relationship between graphical and visualisation capability and metacognition in developing strategic CAD knowledge. This relationship forms the basis of the hypothesis being tested.

### Modelling task

Participants were required to model the part shown in figure 3 utilising the sketch functions and features they judged to be the most expedient. The modelling task was governed by the following design characteristics:

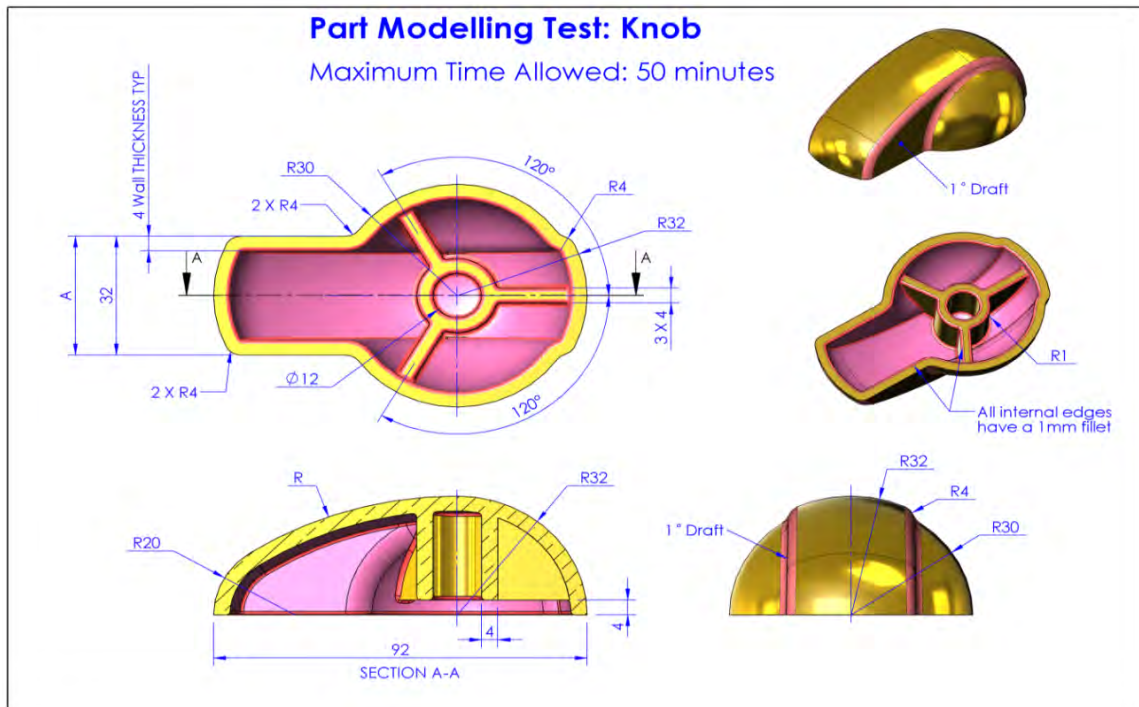


Figure 3. Knob part modelling exercise

1. Successful completion relied on participants' declarative and procedural CAD knowledge which was developed in a previous successfully completed module, coupled with the application of strategic knowledge.
2. Participants' CAD knowledge was further developed over a 12 week period in a subsequent module which participants completed immediately prior to undertaking the modelling task.
3. The need for a strategic approach is even more critical to efficient modelling where models contain doubly curved surfaces.
4. Participants were given 50 minutes to deconstruct and strategically model the part; this was based on an estimate of 2.5 times the time taken to model the part by an expert.
5. The design intent of the knob in relation to the radius of the top curved surface being the same throughout its length and the two principal flat faces having a one degree draft were explicitly stated on the test instructions.
6. Generally learners have much greater difficulty in visualising a 3D object from its orthographic views than they have in visualising and extracting the orthographic views from a 3D representation (Barr, 1999) but this problem was eliminated in this study as participants' were given both pictorial and orthographic views of the model.

The features contained in this knob reveal that the sketch geometry is comprised of lines and arcs, and that the sketched features can be created using a combination of revolve, extrude and sweep processes. The remaining features in the model were applied features such as draft, shell and fillet. In other words, all elements of the modelling task aligned with the typical declarative and procedural 3D CAD knowledge that the research participants had previously encountered, and which are essential for learning to effectively

model using any CAD system. Figure 4 shows one possible strategic approach to building the knob model. While the individual features of the knob model are relatively easy to create, this model could not be created without first mentally deconstructing the task into its key constituent elements and identifying the critical sketch geometry which underpins it. This requires metacognitive as well as graphical and visualisation capability.

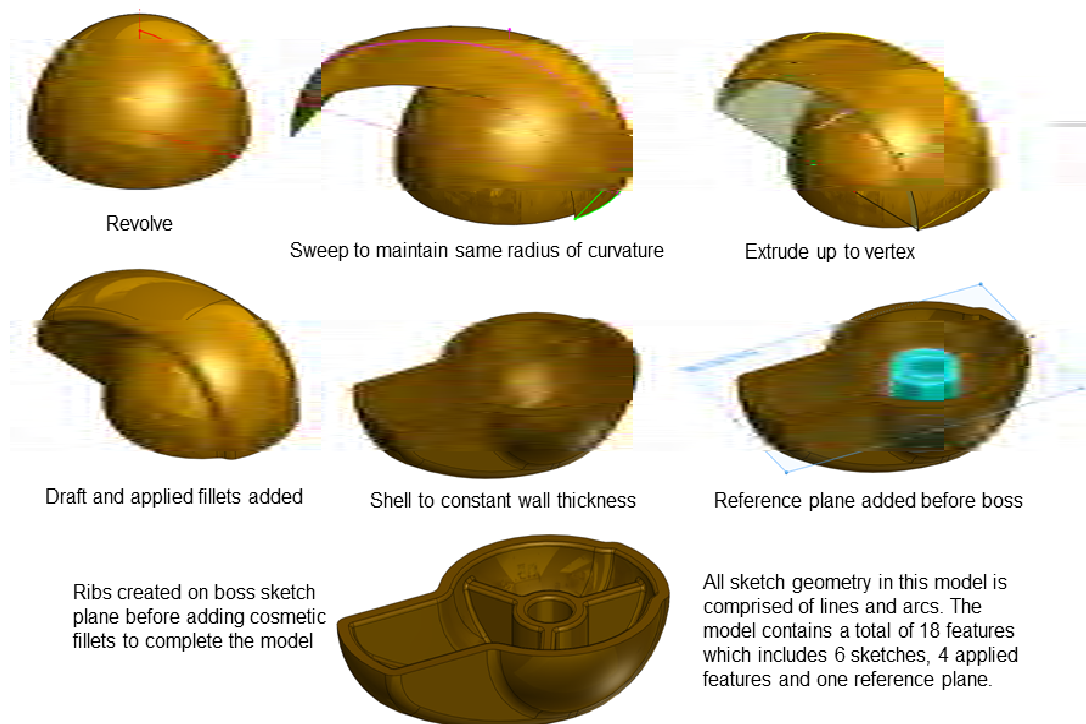


Figure 4. Strategic Solution

**Analytical and observational criteria**

Any meaningful assessment of a digital product model must involve the interrogation of both model sketching strategies and feature definition and creation strategies, as well as the relationship and sequencing of component features (Jankowski, 2002). Based on research and observational studies (Jankowski, 2002; Hartman, 2005; Rynne, 2008; Lombard, 2009) the following checklist represents the basis of an effective workflow for efficient robust parametric solid modelling of non-complex parts when using 3D CAD systems.

- Correct sketch plane selection for base feature sketch
- Optimum model origin for base feature sketch
- Selecting ideal base feature
- Correct part orientation
- Appropriate use of symmetry planes
- Simple sketch geometry
- Automatic and manual sketch relations
- Fully defined sketch geometry with dimensioning
- Intelligent sketch relationships for design intent
- Correct feature sequence
- Parent-child feature relations
- Intelligent feature terminations
- Efficient feature duplication
- Appropriate overall part design intent such that part accommodates planned and unforeseen design modification without feature errors.

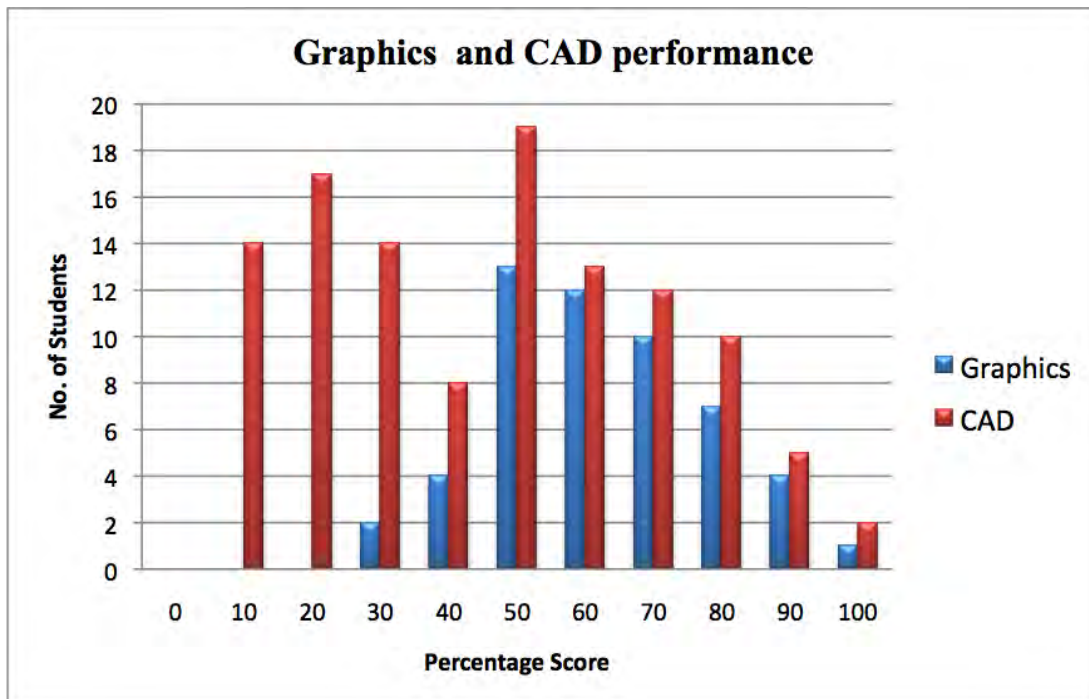


Figure 5. Performance distribution

## Findings

The findings section initially presents the general performance of participants and the relationship between graphics and CAD modelling competency. An analysis of the CAD solutions is presented illustrating empirical evidence that suggests a disconnect between graphicacy capability and its' transfer to developing CAD expertise.

### General performance

To equate participant performance in the graphics and CAD tests, the raw scores from both tests were standardised and graphed on the same scale as shown in figure 5. This resulted in a mean score in the graphics test of 67.3 with a standard deviation of 15.3 while their mean score in the CAD part modelling test was 36.3 with a standard deviation of 23.3 (n = 53). As participants in this research study were randomly selected to reflect graphical

competency across the grade bands the distribution of graphics scores exhibited good normality ( $p = 0.2$ ) as expected, whereas participant CAD scores significantly violate the assumption of normality ( $p = .000$ ) with significantly weaker performance levels in the CAD test than would normally have been expected.

The relationship between geometric competency as measured by a final year graphics examination and CAD modelling expertise as measured by the knob modelling task was investigated using Spearman's rank order correlation coefficient. This nonparametric procedure was used because of the departure from normality of the CAD scores. There was a statistically significant relationship between the two variables ( $r = .62$ ,  $n = 53$ ,  $p < .001$ ) with higher levels of geometric competency associated with higher levels of CAD competency.

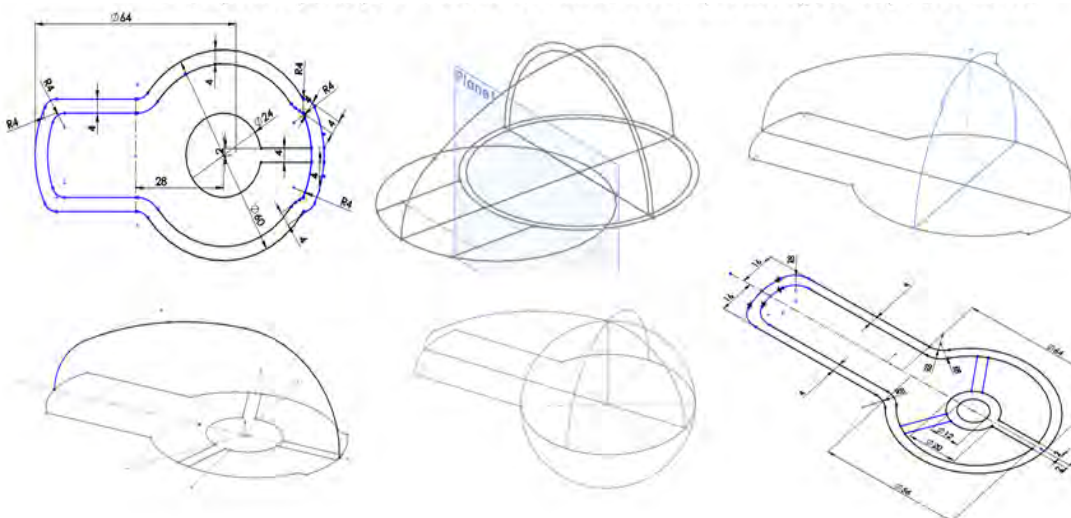


Figure 6. Examples of over reliance on sketch geometry



### Analysis of CAD solutions

The use of the 'roll back feature' gave a valuable insight into the approach taken by the student and often the initial sketch geometry and plane selected indicated the direction of thought. The relationship between visualisation and graphical capability and strategic modelling is apparent on exploration of the completed tasks. Although there were many approaches taken by the cohort to creating the knob model, the majority of participant models that were deficient could be categorised into three general approaches. The first of these approaches is illustrated in figure 6, which shows six examples where participants created orthogonal sketch profiles but not a single feature. While these participants exhibited good CAD sketching skills and correct model origin selection, they seemed to become fixated with drawing the top profile which was not useful for creating features. While these students work shows a clear capacity to execute complex sketch geometry and an ability to sketch on all principal reference planes and even create additional planes, there is a reliance on the top profile for the initial sketch which may be a conditioned response due to the nature of typical product based models. Drawing the offset top profile also suggests the absence of a sufficiently deep level of geometric analysis. From the examples shown it is impossible to effectively complete a functional solution and the inability to complete the task, illustrates a deficiency in the ability of participants to try alternative approaches. The lack of graphical knowledge or an inability to transfer and apply this knowledge suggests an overall inability to create a cognitive model of the part by deconstructing the part geometry into its key constituent elements.

Evidence of a distinctly different modelling approach also emerged and can be best described as a predominantly *Boolean strategy* as shown in the nine examples in figure 7. This is an extension of the first general approach where one, two and sometimes the three orthogonal sketch profiles were extruded to create intersecting features that could be combined. However the approach here is flawed as extrusions do not take into account the double curvature of the model geometry, and combining the intersecting features does not provide correct geometry.

In terms of creating accurate model geometry for the part this approach could never provide a robust intelligent parametric solution.

The third modelling approach was also identified on examination of the student's solutions. Figure 8 shows eight examples of models where participants used a predominantly surface modelling approach.

While this approach is indicative of a more sophisticated analysis of the underlying geometry, a thorough analysis of the model should have concluded that surface modelling is not required at all. Nevertheless some surface modelling approaches did create partially accurate surface geometry which was then closed with planar surfaces to create a water tight volume before converting to a solid model. On occasion this approach created a visually accurate representation of parts of the model, but other surface models repeated the deficiencies found in the Boolean approach by simply creating surface extrusions instead of solid geometry. What is concerning is that the commitment to producing a robust intelligent model was sacrificed to produce

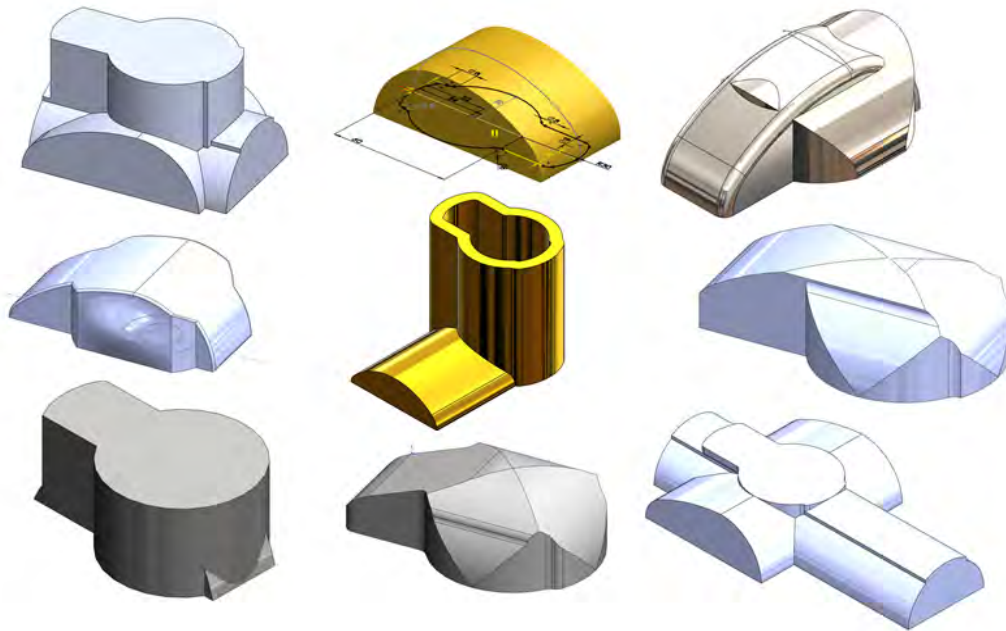


Figure 4. Examples of a predominantly Boolean approach

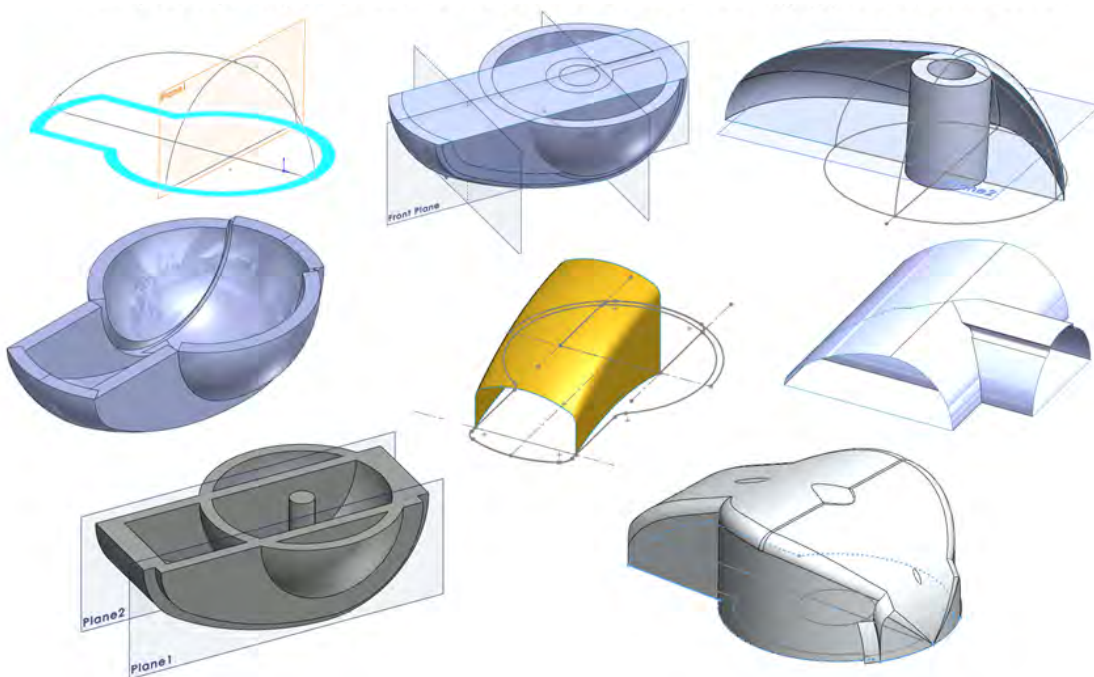


Figure 8. Examples of surface modelling approach

a model that looked good. Apart from the three main categories of errors discussed, other problems encountered included incorrect model orientation due to inappropriate sketch plane selection and the use of a spline instead of tangent arcs for the front profile. Apart from seven participants (13%) who performed reasonably well and scored more than 60%, the overall modelling performance of this group of participants was quite poor, particularly given their prior graphic and visualisation experience and their previous CAD knowledge.

### Discussion

The difference in strategic processing knowledge between experts and novices is the expert's ability to transfer or make use of their store of relevant knowledge. From their superior cognitive models, an expert CAD user is able to solve problems more quickly and with fewer errors than novice users. As in this study, the CAD user usually does not have specific instructions on how to proceed with a modelling task, supporting the need to quickly make optimum strategic choices on how to complete the task. There is a clear distinction between being able to model features using a CAD system and being able to build an effective product model using the same system (Hodgson and Allsop, 2003). The kernel of this distinction is the cognitive modelling and strategic CAD capability of the user.

Given that the research participants had demonstrated prior CAD modelling competency, and comparable competency in graphical and visualisation knowledge, it raises questions about the application, execution and transferability of graphical skills and knowledge. This suggests a major disconnect between graphical and visualisation capability and strategic CAD

modelling. Graphic competency and visualisation of themselves are not enough. Clearly deliberate practice at deconstructing and reconstructing part model geometries is required to overcome the type of modelling difficulties encountered by participants in this study and to ensure that the learner's graphical capabilities translate into strategic CAD modelling capabilities. The cognitive modelling capability required for strategic use of 3D CAD systems needs to be explicitly taught and integrated into CAD pedagogy if the expected benefits of graphicacy are to successfully transfer into effective strategic 3D CAD modelling.

The framework presented in Figure 2 highlights the elements of the problem, while participants had the capability to model the features, and had the required graphic and visualisation capability; the majority were unable to complete an appropriate solution. The modelling impediment to strategic CAD knowledge appeared to be the users' inability to apply metacognitive processes to cognitively deconstruct the model into its key constituent features and underpinning sketch geometry so that it could be effectively modelled.

An apparent trend in the models produced by the students is the singular approach taken by the students. Alternative approaches were not explored in any detail; instead students committed to the primary geometry they produced and fixated on this approach. The general conformity of approach in producing the initial sketch on the horizontal reference plane, suggests a conditioned response as opposed to evidence that the students deconstructed the geometry into its primary constituent parts. An analysis of participant models provides an insight into the type of deficiencies that need to be

addressed to support CAD expertise. Three categories of approach emerged in the models' analysis, a sketch dominated approach, a Boolean approach and a surfacing modelling approach. Although, the various levels of sophistication and capability can be argued across all approaches, evidence of geometric deconstruction was a common and significant deficiency in all models. CAD capability requires effective model deconstruction and analysis.

The overall relatively poor modelling performance in this task was not due to the participants' knowledge of how to operate a CAD system, nor was it due to their lack of graphic or visualisation capability, or insufficient modelling time. While some participants tried different sketch profiles, overall there appeared to be an inability to make strategic CAD modelling decisions. This suggests an apparent disconnect between graphicacy and strategic CAD knowledge.

The models produced suggest an inability to transfer and apply knowledge and skills acquired in a different context and question the nature, depth and definition of the assumption of graphical competency. Jonassen (1999) distinguishes two types of performance modelling: behavioural modelling and cognitive modelling. Behavioural modelling demonstrates how to perform the activities identified, while cognitive modelling articulates the reasoning that learners should use while engaged in the activities. In their research on the knowledge structure of experts and novices, Koubek and Salvendy (1989) found that experts organised knowledge around deep underlying principles whereas novices organised knowledge around shallow surface features. To better facilitate CAD decision-making and CAD reasoning, students need to acquire the

metacognitive capability to process and deconstruct modelling tasks.

The approach of a student whose computer crashed half way through the test is testament to strategic CAD modelling. This student re-drafted the solution in 20 minutes and produced a model very similar to the proposed strategic solution shown earlier in Figure 4. The modelling feature sequences of both solutions were almost identical except for two principal differences. The first of these was at stage three, where the student used a mid-plane end condition extrusion instead of an up to vertex extrusion in both directions which he would have had to use to achieve the desired robust design intent due to him locating the sketch geometry on the symmetry plane. The problem with the mid-plane extrusion is that this will not update at all if the width of the sweep is changed which is a major flaw. The second difference was that while the student quite cleverly decided to create the boss and the ribs as a single feature, he forgot to allow for both sides when creating the boss sketch circle resulting in the internal and external boss diameters being incorrect. While the likelihood is that this student would have modelled the part more efficiently the second time round, overall, his performance demonstrated that participants had ample time to model the part provided they used the earlier time to successfully deconstruct and plan an effective modelling sequence.

Poor cognitive modelling leads to poor 3D CAD modelling. Advanced beginners cannot be turned into expert users by simply telling them what the expert knows; rather they must acquire the skills and strategies to build coherent cognitive models as it is strategic 3D CAD knowledge that differentiates the expert from the novice user. Users will not be

able to efficiently model without being able to first create a cognitive visual model of it. Without this cognitive model users cannot mentally decompose the geometry correctly to know where to begin with the base feature of a part model and how best to add subsequent features.

### **Conclusion**

This paper suggests an underlying weakness in the understanding of our definition of graphicacy and the outcomes that define graphical capability. The application and transferability of graphical knowledge and skills must be at the core of educational outcomes. Although there is a clear relationship between graphicacy and efficient CAD modelling, without

prescription, there is an inherent weakness in students' capacity to utilise graphical skills and knowledge. The proposed cognitive 3D CAD framework implies that knowing and understanding correct part modelling procedures and having the relevant knowledge of the software tools is not sufficient for efficient part modelling. Neither is it enough to have graphic and visualisation capability. The development of strategic 3D CAD modelling knowledge through metacognition and freehand sketching applied appropriately to develop a cognitive modelling skillset should become an integral part of how parametric modelling is taught in schools and colleges. Only then can the learner effectively use 3D CAD as a design decision making tool.

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## Eye-tracking experiment to test key emerging principles of visual communication of technology

Cheng-Siew Beh, Kevin Badni & Eddie Norman

### Abstract

*The aim of this paper is to examine people's eye reading patterns on technological information presented in 2 dimensional visual forms. This is in relation to testing the principles of visual communication (VC) applied on those visual representations and whether they obtained a similar (if not the same) patterns of recognition as suggested by the key emerging principles (KEP) of visual communication of technology (VCT) that had been derived from a literature review (Beh & Norman, 2010). An eye-tracking experiment was designed with an evaluation strategy targeted at gathering qualitative and quantitative data of reading patterns. The visuals selected for the experiment represented a comparison of three prepared in the 21<sup>st</sup> Century where there was evidence of their effectiveness in communicating technological information with visual representations with similar purposes and of acknowledged quality from the 16<sup>th</sup> Century. Five participants took part in the study and verbal protocols were recorded alongside the eye-tracking experiments. The quantitative results concerning eye movements and the qualitative indications of associated understanding were consistent with the KEP derived from the literature review.*

### Introduction

A literature survey was conducted which explored the visual communication of technology (VCT) in designing, and thereby links to creativity and innovation (Beh & Norman, 2009, 2010). In addition, claims of visual communication (VC) as a tool to facilitate creative thoughts for cognitive modelling, and then resolving or obtaining design outcomes were found. This complex chain of events has been asserted throughout many decades within the development of design, technology and education (Ashby & Johnson, 2004; Baynes, 2009; Carlson & Gorman, 1992; Codone, 2005; Curtiss, 1987; Ferguson, 1993; Finke et al., 1988, 1989, 1992; Middleton, 2005; Norman, 1998; Weber et al., 1989, 1990, 1992). However, there is little empirical research evidence to support these assertions (Beh & Norman, 2010). Within the literature search, key emerging principles (KEP) of the VCT were developed (Beh & Norman, 2009, 2010; Beh et al., 2010). The practice of VCT, in fact, has been significant since the Renaissance, and particularly during the industrial revolution. It has been a key communication and concept development tool for designers/inventors, engineers, clients, manufacturers and others (Baynes, 2009; Ferguson, 1993; Baynes & Pugh, 1978).



This paper reports empirical evidence, which was being sought to validate the KEP of VCT from the readers' perspectives using the eye-tracking method. The eye-tracking experiment involved comparisons between visual representations created in the 21<sup>st</sup> Century with those with similar purposes from the 16<sup>th</sup> Century. All the visuals used in the experiment either represented acknowledged good practice, or there was independent evidence of their effectiveness.

### Background literature

This section reports two areas of literature foci: 1) *emergent principles of visual communication of technology*; and 2) *eye-tracking and its application*.

#### ***Emergent principles of visual communication of technology***

The key emerging principles of VCT were derived from Tufte (1990, 1997, 2006) who provided a range of comprehensive principles and techniques to develop effective quantitative and statistical graphical visual information; Rand (1971, 1985) who gave perspectives on graphic design for persuasive visual communication; Ferguson (1993) who presented the history of engineering design and visualisation tools; and Thomson (1979) who offered graphic principles for engineers.

The emergent VCT principles were based on common elements identified from these authors. Namely, the representation's capability in facilitating *comparison* to reveal connections and *relationships*; unity of *form* to accentuate *function*; *precision* of data to communicate accuracy or *truth*; and all graphical structures should be *simple* in design form, but *complex* in carrying data, in short, the emergent VCT principles are:

1. COMPARE > RELATIONSHIP
2. FORM > FUNCTION
3. PRECISE > ACCURACY/TRUTH
4. SIMPLE IN DESIGN; COMPLEX IN DATA

Each of these VCT principles can be elaborated in relation to two different concerns of: 1) *technical and technological matters*; and 2) *graphic arts*. The detailed elaboration and articulation of the established key emerging principles of VCT is as illustrated in (Beh et al., 2010).

#### ***Eye-tracking and its application***

Many research studies in the advertising and design fields have used eye-tracker devices to gather extensive data and have provided important findings for the improvement of the presentation of consumer goods. The eye-tracking device allows a large amount of statistical data concerning eye movements to be obtained. However, Jacob and Karn (2003) emphasised that some common details e.g. scanning path, number of gazes, percentage of participants fixating an area of interest, and time to first fixation on target area of interest were interesting measures for research, but that they have often been overlooked during analysis in many studies.

The uses of eye-tracking methods have made possible the close examination of the conscious and unconscious gaze movement of a respondent in visual system research (eyetracker.co.uk; system-concepts.com). The human visual system starts with eye movements, which are linked to perceptual systems; it is the close relation of these movements to attentional mechanisms, saccades that can provide insight into cognitive processes, e.g. language comprehension, memory, mental imagery and decision making (Richardson & Spivey 2004: 2).

Visual systems research in the areas of advertising and design commonly focus on the consumers' behaviour, particularly on commercial messages for products. This is supported by Richardson and Spivey (2004: 17) as they suggested that eye-movement behaviour of consumers can determine immediate perceptual factors and decision-making processes. Richardson and Spivey (2004: 15) cited early empirical findings from Perky (1910), Clark (1916), Stoy (1930), Goldthwait (1933) and Totten (1935) that the frequency of eye movements increases during mental imagery. In addition, their recent work suggests that eye movements were related to both memory of specific perceptual experience and cognitive acts of imagination (Richardson & Spivey 2004:15). Levy-Schoen (1983: 66) emphasised, *'to the extent that eye movements are reliable correlates of the sequential centring of attention, we can observe and analyse them in order to understand how thinking goes on.'* The use of eye-tracking for design-based research by Fischer et al. (1989), Pieters

et al. (1999), Russo and Leclerc (1994), Malach et al. (2005), and many other works reported in Jacob and Karn (2003: 582-584) were founded on similar grounds; namely the correlation of eye movements and visual perceptual systems.

The eye-tracking metrics (Figure 1) could provide useful guidelines for evaluating reading-patterns of visual information; and subsequently, the effectiveness of the applied VCT principles on those visuals.

For this research study, these types of eye-tracking data have been used to trace the eye movements involved during reading and comprehending technological visual information. The aspect of capturing the message-perceptions associated with the visual information was accomplished using the conventional research methods of questionnaires and interviews.




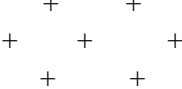
	(+)	1.	Frequency of gaze (number of fixations) on each area of interest > reflect the importance of that area/element of display
	(+)	2.	Scanpath (sequence of fixations) and transition probability between areas of interest > can indicate the efficiency of the arrangement of elements in the visual surface
	(-)	3.	Duration of fixation (gaze duration) > longer fixations reflect difficulty in extracting information from display
	(-)	4.	Number of fixations (at overall visual surface) > reflect poor display of visual elements

Figure 1. Eye-tracking metrics (adapted from Jacob & Karn 2003: 585; Josephson 2000: 64)

### **Validating the key emerging principles through eye-tracker research**

The eye-tracking experiments allow the key emerging principles (KEP) derived from literature describing the intentions of the originators of the visuals to be validated against the interaction as experienced by a reader. The eye-tracker allows the researcher to find out whether what a person sees and has understood could confirm the effectiveness of certain visuals, particularly for those where there is evidence that they represent good practice, either in the past or in current situations.

### **The selection of the visual representations for the experiment**

A total of 6 representations were selected for this viewing experiment. These 6 visuals comprised: 3 from historical evidence (Besson, 1578; d'Ocagne, 1862; da Vinci, 1500) taken as good examples from Ferguson (1993); and another 3 from current representations which have shown some evidence of effective impact in communication (Storer, 2005; Lofthouse & Bhamra, 2005; Beh & Norman, 2009), as shown in Table 1.

These visual representations were selected because they supported designing and innovation, and they could be put into the three categories of VCT principles: 1) *Compare > Relationship*; 2) *Form > Function*; 3) *Precise > Truth*. Figures A and B (Table 1) were selected with the intention of allowing the viewers to compare relationships and the interaction between humans and technologies, which communicate extensive messages about products, processes, proportions, materials, etc. Figures C and D (Table 1) were selected based on their ultimate use as aids or tools to guide further design decisions. Figures E and F (Table 1) were

selected for the means of communicating designed or studied details, informing about extensive technological aspects or features for further understanding and inspiration purposes.

### **Methodology**

The experiment was set up using an eye tracker device that attached to a bicycle helmet and was connected to a computer workstation, LCD projector and a laptop, as shown in Figure 2. The selected 6 visuals were shown via PowerPoint slide projection on the wall screen for scanning. The scanning process was recorded for capturing individual's visual reading patterns, and hence testing the principles of VCT applied on those representations. This visual test only requires the viewers to respond to what they have seen and describe what they have understood from the visuals.

The 6 visuals were put into 3 sets for the research study. They were:

1. Visuals without language explanation;
2. Visuals with language explanation (accompanied by captions and interview prompts);
3. Visuals placed in 3 pairs for comparison.

The recording system involved a small camera device and an audio recorder. The audio device recorded the interview prompts and responses; whilst, the camera that attached to a bicycle helmet was put on the viewer, and was calibrated for every individual's eyes.

Participants remained anonymous in all published outcomes; however, some personal details were gathered for research data, particularly the participant's academic background/ prior knowledge, cultural background, age and gender

groups, as these factors may or may not influence the research outcomes. Loughborough University's 'Ethical Clearance Checklist, Briefing and Consent for Participants' procedures were followed.

***First set of experiments – visuals without language explanation***

Participants were asked to describe what they “see” in each of the 6 visuals projected. Some guiding questions (Figure 3) were drafted to use as prompts during this set of tests, in case, for example, the researcher needed to determine or clarify why viewers were looking at some spots but not others, or have a particular pattern of descriptive results. However, these questions were not used as the participants’ responses seemed quite sufficient and clear for the analysis of this aspect of the study. They are included here in order to clarify its scope.

***Second set of experiments – visuals with language explanation (accompanied by captions and interview prompts)***

Participants were asked to describe what they “understood” in each of the same 6 visuals projected, only this time captions were added to the visuals. Additionally, some semi-structured questions (Table 2) were used as prompts during the scanning. This was to help those participants who needed some hints to help them describe what they have seen and understood, what they were not so clear about, or what they have not yet stated in the first set of experiments. The semi-structured questions were based on four focus areas: 1) **Obvious message**; 2) **Obvious details**; 3) **Hidden or interpreted details**; and 4) **Interpreted or inspiration message**. The questions correspond to the visuals as illustrated in Table 2.

***Third set of experiments – visuals placed in 3 pairs for comparison***

After viewing the individual images, the same 6 visuals from the second set of experiment were placed in 3 pairs for comparison. This was intended to allow the participants to have another chance to compare the similar relationships or intentions of each set of representations, if they had not seen the relationship in the first place. The participants were asked to describe any similarities in the ways these pairs of images communicated.

**Samples and recordings**

Five participants (P) completed the piloted eye-tracking experiment. Their academic backgrounds were: Design and Technology (P1); Materials Sciences and Engineering (P2); Art and Design/Fine Art (P3); Industrial Engineering (P4); Industrial Design (P5). They were a purposive sample in that they represent particular academic categories of students. They were also selected for their different cultural backgrounds in terms of where they grew up: two from the UK; one from Cyprus; one from Singapore; one from Mexico; and they were asked for their learning preferences for an initial comparative study.

During the experiment, 2 of the respondents’ recordings were captured with some missing eye-scanning statistical data. Therefore, it was not possible to generate the scanning path patterns. However, the raw sources of eye-tracking video (with eyes fixations), and the descriptions of what they have seen and perceived were safely recorded and these data can still be used for further analysis. The other 3 respondents’ recordings were successfully and fully captured, and were able to be used for the full scanpaths analysis.

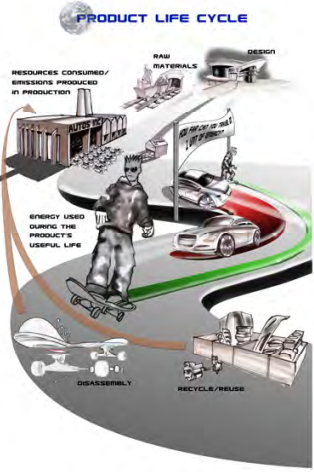
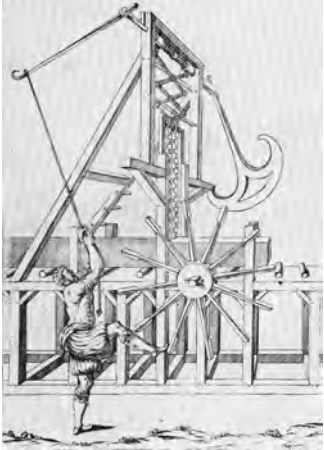
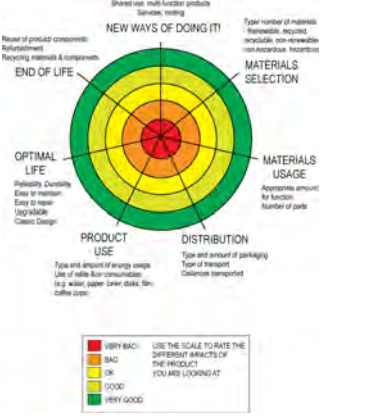
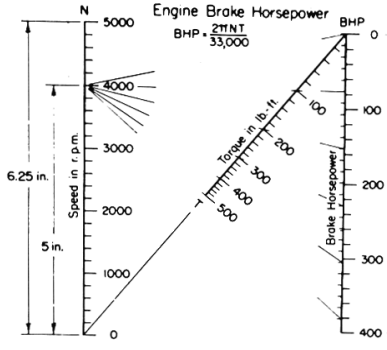

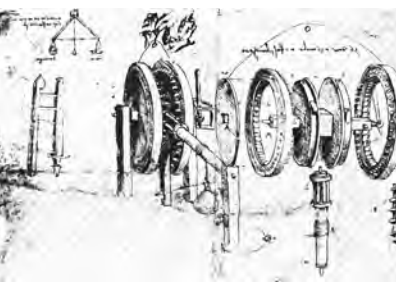
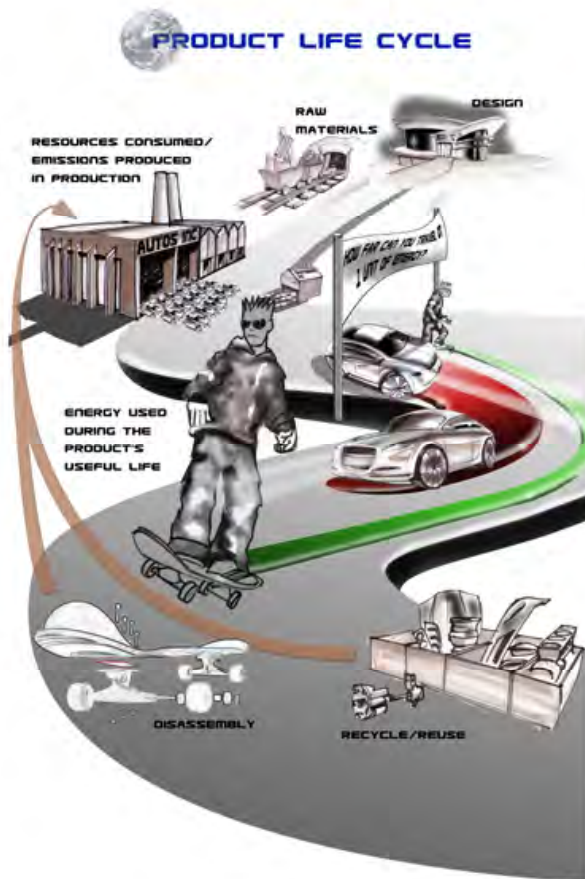
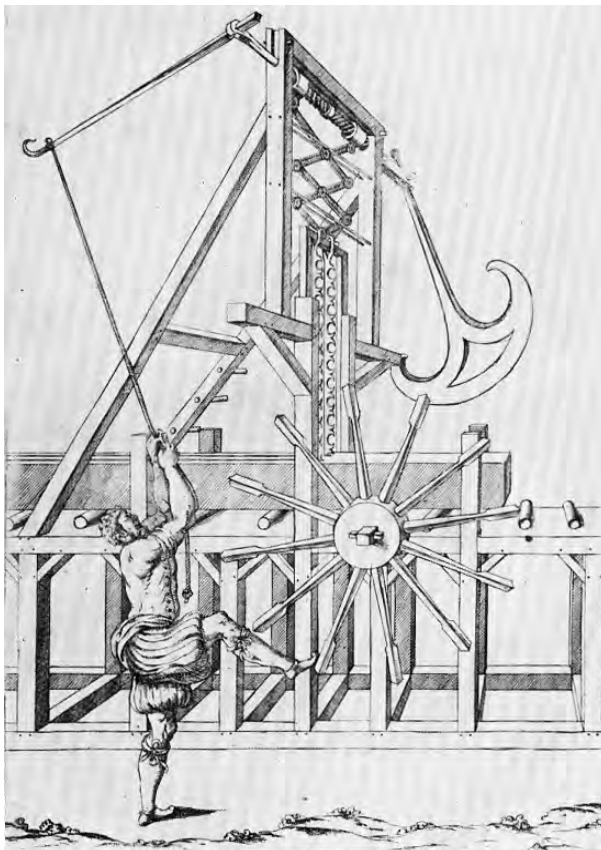
VCT principles	Rationale of visuals' selection	Current examples (have evidence of effective impact in communication)	Historical evidence (Ferguson, 1993)
<p style="text-align: center;"><b>1</b></p> <p style="text-align: center;"><b>COMPARE &gt; RELATIONSHIP</b></p>	<p>Comparing relationships and interaction between humans and technology; communicating extensive messages about products, processes, proportions, materials, etc.</p>	 <p style="text-align: center;"><b>(A) Sustainable design poster</b> <i>(Storer, 2005)</i></p>	 <p style="text-align: center;"><b>(B) Manual up-and-down sawmill</b> <i>Jacques Besson, 1578 (Ferguson, 1993:79)</i></p>
<p style="text-align: center;"><b>2</b></p> <p style="text-align: center;"><b>FORM &gt; FUNCTION</b></p>	<p>Used as an aid or tool to guide further design decisions.</p>	 <p style="text-align: center;"><b>(C) Ecodesign web for isotonic drink bottle concept</b> <i>(Lofthouse &amp; Bhamra, 2005, adapted from the LiDS-wheel, Hemel, 1995)</i></p>	 <p style="text-align: center;"><b>(D) Nomogram</b> <i>Maurice d'Ocagne, 1862 (Ferguson, 1993:151)</i></p>
<p style="text-align: center;"><b>3</b></p> <p style="text-align: center;"><b>PRECISE &gt; TRUTH</b></p>	<p>Communicates designed or studied details, informing about extensive technological aspects or features for further understanding and inspiration.</p>	 <p style="text-align: center;"><b>(E) Kite-Info-Poster</b> <i>(Beh 2009, adapted from Key Stage 3 (for 11-14 year olds) Kite Resource Pack, Norman &amp; Cubitt, 1999)</i></p>	 <p style="text-align: center;"><b>(F) Ratchet device</b> <i>Leonardo da Vinci, 1500 (Ferguson, 1993:88)</i></p>

Table 1. Six visuals for the eye-tracking experiment

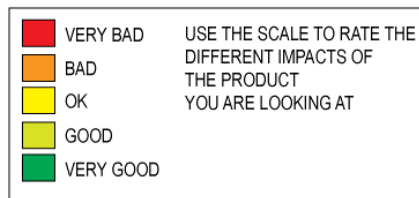
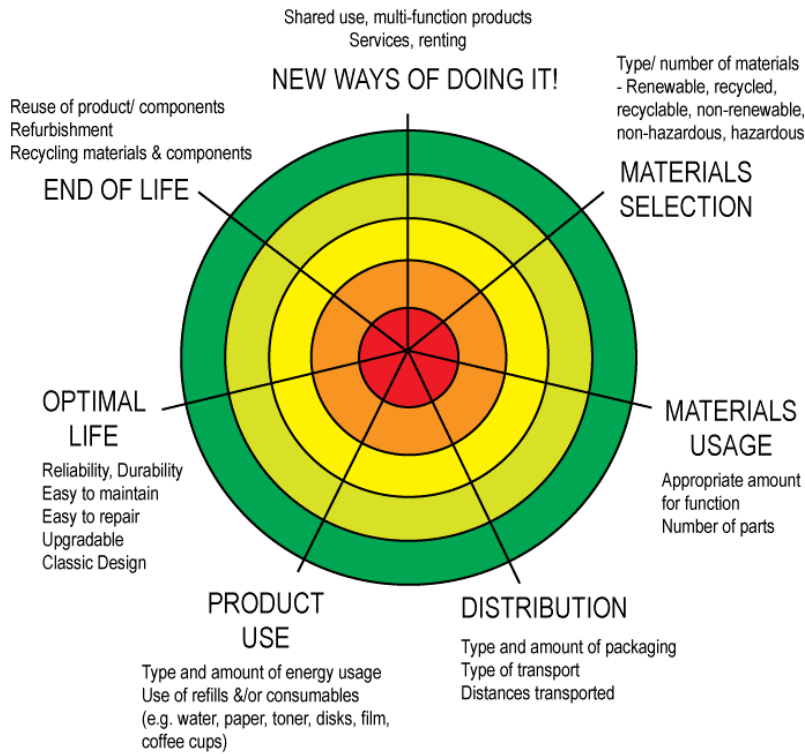


**(A) Sustainable design poster**  
(Storer, 2005)



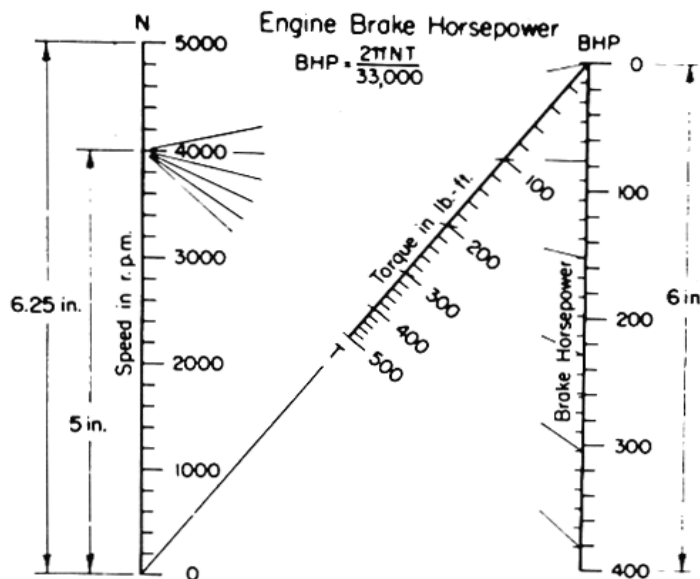
**(B) Drawing of A Sawmill Machine**

(Image now in the public domain;  
Besson, J., 1578, *Theatre des  
Instrumens Mathematiques et  
Mechiniques*, pl. 14; reproduced in  
Ferguson, 1993, p. 79;  
used with permission of MIT Press)



**(C) Ecodesign web for isotonic drink bottle concept**

(Lofthouse & Bhamra, 2005, adapted from the LiDS-wheel, Hemel, 1995)

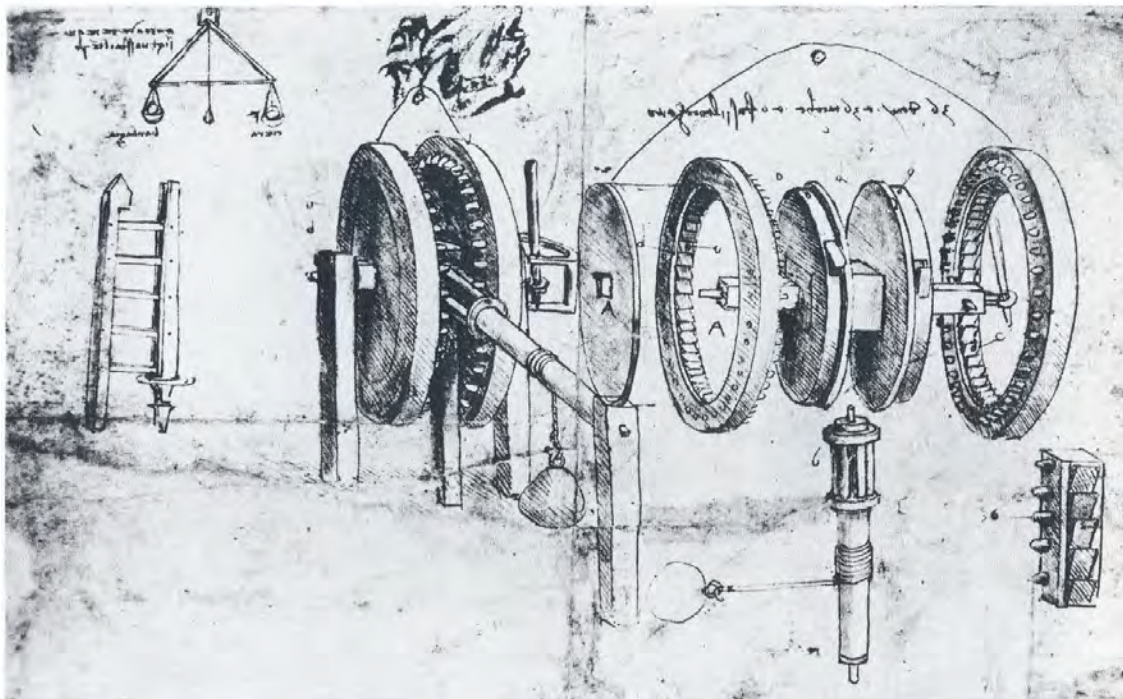


**(D) Nomogram, A Mathematical System, Maurice d'Ocagne 1862**

(image now in the public domain; Vierck, C. J., 1958, *Graphic Science*, p. 647; used with permission of McGraw Hill; reproduced in Ferguson, 1993, p. 151)



(E) Kite-Info-Poster (Beh 2009, adapted from Key Stage 3 (for 11-14 year olds) Kite Resource Pack, Norman & Cubitt, 1999)



(F) Exploded And Extended Drawing of Ratchet Device, da Vinci 1500

(image now in the public domain; 1973-1975, *11 Codice Atlantico*, vol. 9, p. 808; reproduced in Ferguson, 1993, p. 88; used with permission of MIT Press)





Figure 2. Layout of the eye-tracking experiment

**Possible questions for interview prompt – Set 1:**

**Questions related to “Spotting”**

*You seem to scan back and forth a few times from spot A to spot B,*

- 1. Can you explain why you did that?*
- 2. What were you thinking at that moment?*
- 3. What have you gained/understood from that spot?*
- 4. Is the action of looking back and forth helping you to understand more/the message?*

**Questions related to “Duration”**

*You have stared at a spot for quite some time,*

- 1. What have you seen?*
- 2. What were you trying to understand?*
- 3. Is there any other message you think it might imply?*

**Questions related to “Sequence” (Scan path)**

*You have read the poster from e.g. right to left (a certain pattern),*

- 1. Can you explain why you did so?*
- 2. I've noticed that you have changed the pattern of reading the visual, please describe your findings after doing so.*

Figure 3 Semi-structured questions for the interview prompts – Set 1


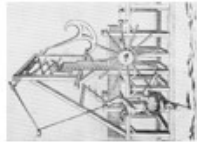
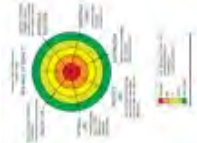



	Visual-A	Visual-B	Visual-C	Visual-D	Visual-E	Visual-F
Question categories						
<b>1. Obvious Message</b>	What is the message of this poster?	What does this machine do?	What is the purpose of this diagram?	What is the purpose of this diagram?	What is the message of these posters?	What do you see in the drawing?
<b>2. Obvious Detail</b>	What are the main stages of the life cycle of a product?	What are the key elements of the machine?	How does the colour scheme work?	When the r.p.m = 4,000 and torque = 400 units, what is the horsepower of a brake engine (BHP)?	What are the forces acting on the kite while flying	What are the main elements in this device?
<b>3. Hidden/ Interpreted Detail</b>	What are some of the key strategies to improve the environmental performance?	What does the operator (human figure) do in the drawing?	If you were asked to aim for "reuse, reduce and recycle", what does the diagram suggest you could do?	If the r.p.m stays the same, what could happen to the torque and BHP?	How is a kite balanced?	Can you describe how the device operates?
<b>4. Interpret/ Inspiration Message</b>	Does this poster inspire you in some way? How?	What are the factors that you need to consider while preparing to build this machine?	How could you use this tool to improve your designing (from an ecodesign perspective)?	If you were to design a less powerful engine, what could happen to the r.p.m, and torque?	Do these posters inspire you to have new ideas for kite design? In what way?	What are the factors that you need to consider if you were preparing to build a device of this kind?

Table 2. Semi-structured questions for the interview prompts – Set 2

### Eye-tracking results

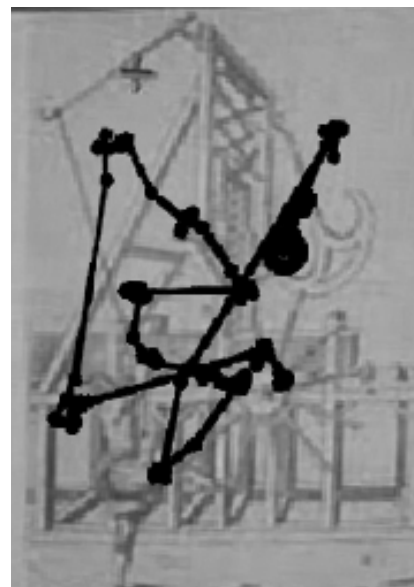
The intention of the eye-tracking is to confirm that what the participants said was in agreement with what they have viewed and the images they have processed in their mind's eye to understand the messages.

Figure 4 is the raw video recording sources of the participants' viewing scanpaths. Dots and lines on the images (Figure 4) are the scanpath traces, indicating the eyes' movements over the area of interest (AOI). These raw sources were difficult to analyse as the movements were all in milliseconds, making it too fast

to identify the respondents' eye movements, patterns and their fixations on the AOI. These representations of the scanpaths were then analysed in parallel with the respondents' protocol transcripts. The time spent in understanding the visual messages and the prompted questions are also shown together with the analysis in Table 3.



Visual-A Video Clip



Visual-B Video Clip

Figure 4. Pair 1 – participants' eye-tracking scanpaths

**Visual-A from participant 3 (P3):**

Prompts (P):

**P1.1** What is the message of this poster?

**P1.2** What are the main stages of the life cycle of a product?

**P1.3** What are some of the key strategies to improve the environmental performance?

**P1.4** Does this poster inspire you in some way? How?

**Findings: Scanpaths, Areas of Interest with Protocol Transcripts**

Area of Interest (AOI)	Scanpath Frames	Prompts (P)	Participant's responses	
			sec	descriptions
1. Human on skateboard			0-8	<i>I see a boy on a skateboard and...</i>
2. Dissassembly				<i>...another thing below him</i>
3. Banner & Car			9-25	<i>Behind him is a car that is going quite fast, and another car, then there is a banner or finishing line with another skateboard indicated.</i>
4. Recycle/Reuse			26-48	<i>Oh, there is a recycling box, a representational cycle or recycle of some kind.</i>

Table 3. The analysis of scanpaths, AOI and protocol transcripts for visual-A of P3

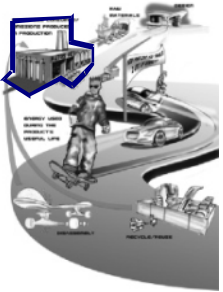
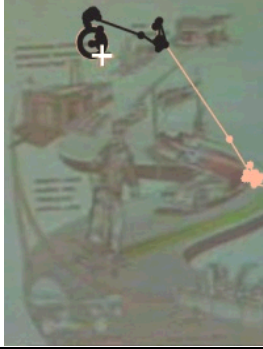
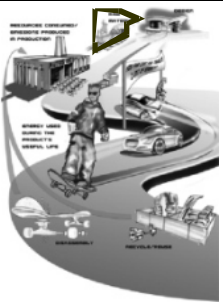
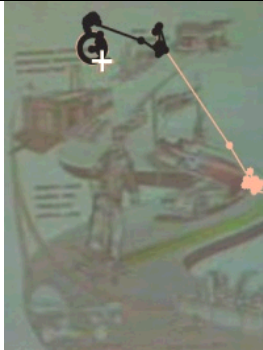


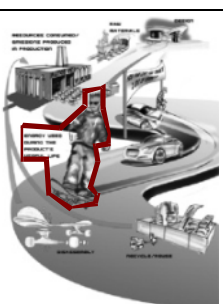

	Area of Interest (AOI)	Scanpath Frames	Prompts (P)	Participant's responses	
				sec	descriptions
5. Production				52-59	<i>Ah...ok, so we have a factory, which has...</i>
6. Raw Material					<i>... raw materials delivered to it.</i>
7. Design				1:00-1:08	<i>Right at the back of the road there is a design center.</i>
				1:09-1:19	<i>I guess, what I am seeing is a journey of a product, but there are 2 products, a sketeboard and a car.</i>

Table 3. (continued)

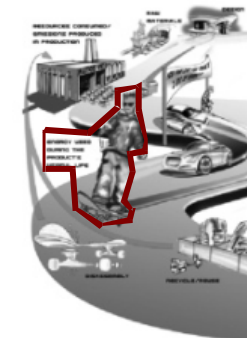
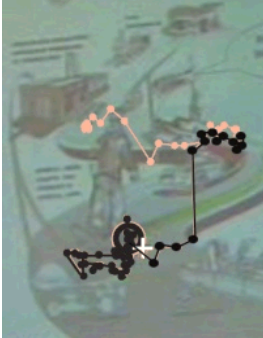
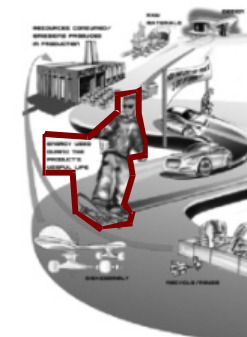
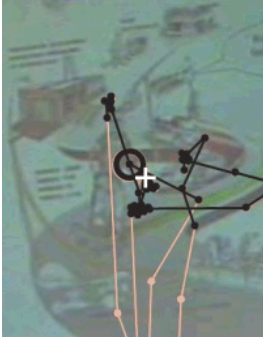
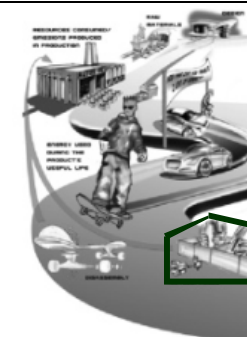
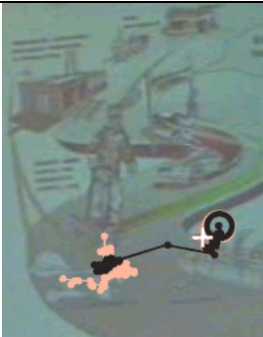

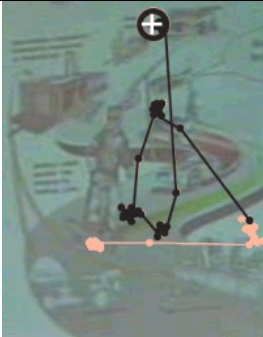
Area of Interest (AOI)		Scanpath Frames	Prompts	Participant's responses	
			(P)	sec	descriptions
		<b>P1.2</b> What are the main stages of the life cycle of a product?	29	<i>It is about product design,...</i>	
				<i>...then is manufactured for more materials, which shows consumer resources like fuels, produces a mission, the products were then used and during its useful life,...</i>	
				<i>...disassemble and recycle.</i>	
		<b>P1.3</b> What are some of the key strategies to improve the environmental performance?	14	<i>Fuels efficiency, also the materials that can be reuse and where they sourced from.</i>	

Table 3. (continued)

**Pair-1 (visuals A & B) results and their links to VCT principles**

The initial in-depth visual analysis being reported here only covers the first pair of visual representations (one from the current practice; another from the 16<sup>th</sup> Century example) of 3 participants. A similar and consistent pattern of the

sequence of eye fixations between AOI was shown amongst the 3 respondents. Table 4 displays the sequential pattern and duration of their eyes' fixations on certain AOI. This demonstrates the respondents' actual reading patterns of visual information.

**Findings: sequence of eye fixations on AOI**

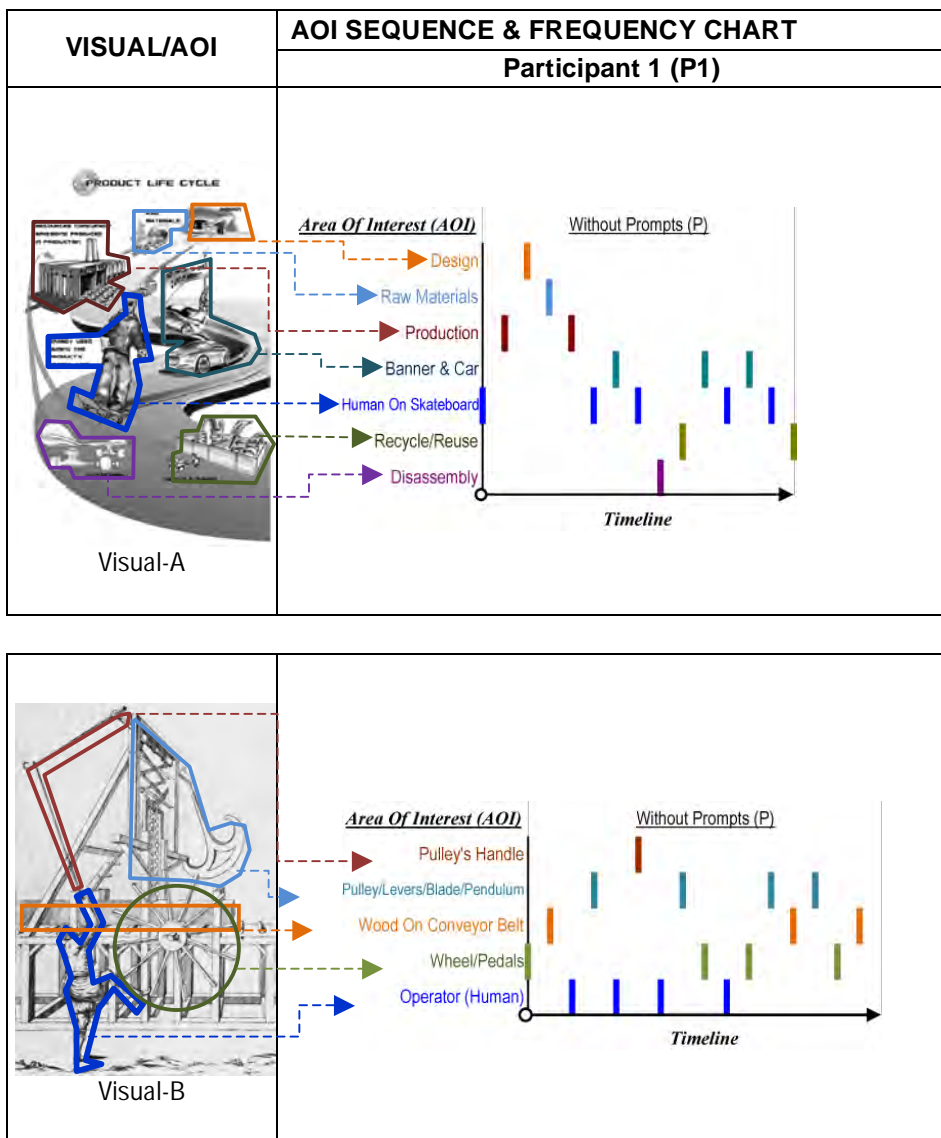


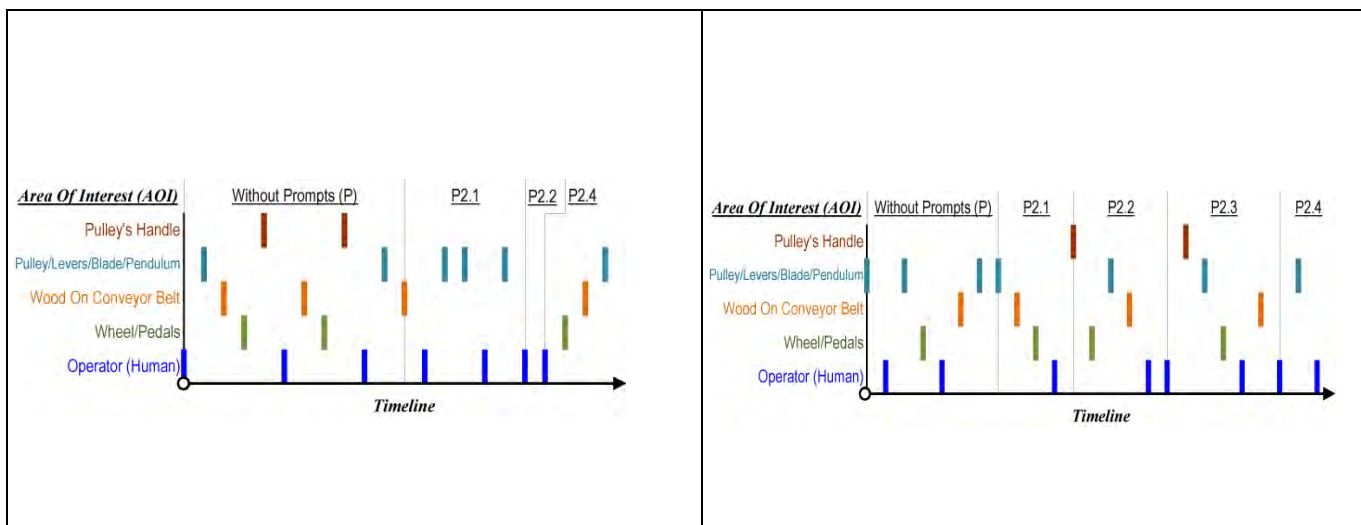
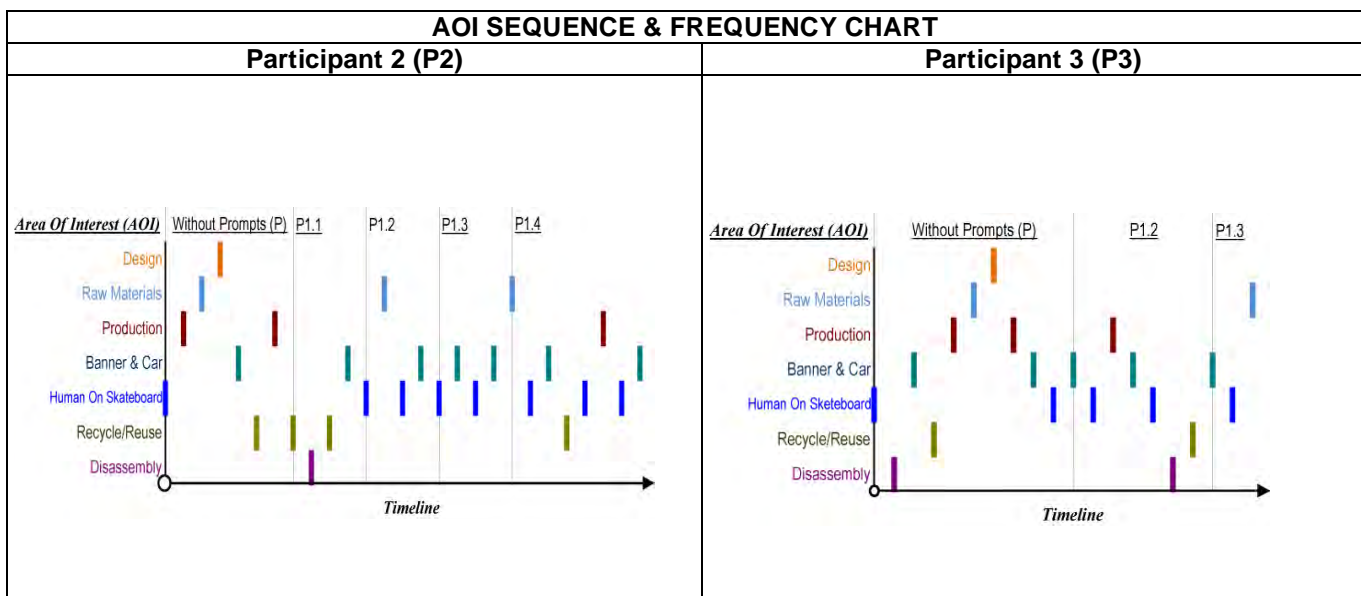
Table 4. Pair 1: Three participants' eye-tracking sequence chart

**Pair-1: The journey and patterns of reading visual-A (analysed from Table 4)**

- All 3 respondents first fixed their eyes on the human figure (the boy), and then to the objects, initially those nearest and gradually moved outward. [Note: Production factory;

car with the banner; disassembly tools; and recycle/reuse box are the 4 AOI that circled the boy on skateboard. The further away AOI are raw materials and design buildings

**AOI SEQUENCE & FREQUENCY CHART**





- Two of them (P1 & P2) looked at the production factory right after fixing their eyes on the boy with the skateboard, following by scanning through the raw material and design buildings.
- One of them (P3) scanned through the disassembly tools and recycle/reuse box right after fixing their eyes on the boy with the skateboard, and then briefly fixed her eye on the car and production factory, and later scanned through the raw material and design buildings.
- All 3 respondents showed significant patterns of repeatedly looking back at the boy on the skateboard and the car with a banner when they recognised that the poster is about the life cycle of two products (referring to the respondents' protocol transcripts, and the analysis shown in Tables 3 & 4). [Note: They were able to identify that the poster is about two products: the boy's skateboard and the car behind the boy.]
- The scanpaths sequence chart (Table 4) depicts that the 'Human on Skateboard' and 'Banner & Car' are the most frequent AOI that all participants looked back and made reference to. [Note: This pattern suggests that the viewers were trying to make connections between the two main characters of the poster, and subsequently they were referring to other AOI/objects around these two in order to find further obvious or hidden messages.]

***Pair-1: The journey and patterns of reading for Visual-B (analysed from Table 4)***

- The starting point of fixations on the AOI for all 3 participants was slightly differing in Visual-2. However, all 3 of them recognised that the key visual elements of this illustration (Visual-B) are about the machine and its operation. Thus, they either looked first at the machine or the human figure (the operator). [Note: The main visual elements of this illustration are the machine and the operator; however, the researcher divided the AOI based on several key devices of the machine for tracking details of the studied visual.]
- P1 began the eye fixation on the AOI of 'Wheel & Pedal' (the operator's foot is on the pedal of the machine's wheel); P2 started with the AOI of 'Operator/Human'; and P3 looked at the 'Pulley/Levers/ Blade/Pendulum' as the first AOI (the operator's hand is pulling the handle that links to the pulley which operates the levers, blade and pendulum). [Note: Although the participants did not start at the same point of the detailed AOI, they did show similar patterns of making comparison and connections to those shown for Visual-A. The scanpaths showed them looking for links between the human and objects (parts of the machine in Visual-B). Initially those AOI nearest to the human were scanned and then the participants gradually moved outwards, as the device parts they looked at first were those connected to either the operator's hand or foot.]

- The AOI of ‘Operator’ and ‘Pulley/Levers/Blade/Pendulum’ were the most frequent AOI that all participants looked back and made reference to (sequence chart of Visual-B, Table 4), second frequent AOI was ‘Wheel & Pedal’. [Note: These AOI are immediately linked to the operator.]

***The comparison of the similarities for pair-1 (visuals A & B)***

The interpretation at this section is based on Tables 5, 6 and 7. Tables 5 and 6 illustrate the messages perceived by the 3 participants, either from what they have understood or interpreted, in relation to the AOI from their scanpaths. Table 7 shows the 5 participants’ understanding/interpretation of the messages with the time of the descriptions within the protocol. The data were drawn from the protocol transcripts.

All 5 respondents (3 with full records of visual recordings and analyses, and protocol transcripts; 2 with only raw visual sources and protocol transcripts) agreed that both visuals tell the story of product(s) and their associated technologies or processes (Table 7). Three of them (non-engineering background) emphasised that both visuals use human depictions as a reference to provide messages about the

product(s) depicted, e.g. reference to some sort of dimensions, processes involved and/or functions of the products in relation to the environment or technology around them (Tables 5 – 7). Overall, the representations were reported as providing perspectives of messages or stories relating to the content of the visual information; where the human becomes the centre point for the readers to connect and explore relationships to the surrounding AOI. Thus, the human figure provides a starting or reference point for the readers.

***Pair-2 (visuals C & D) results and their links to VCT principles***

An in-depth visual analysis (as of what the viewers actually ‘see’) for 3 respondents as in pair-1 analysis has not yet been completed. However, this section will report the findings of 5 participants, based on their protocol transcripts (as of what they ‘said’ and ‘understood’) of visuals C and D (refer to Tables 1 or 2), and simple observation from the raw data of eye-tracking. Similar and consistent patterns of searching for a form of matrix were demonstrated amongst the 5 respondents.







No.	AOI	Understood/interpreted message		
		Participant 1 (P1)	P2	P3
1.		All 3 participants pointed out that they were 1 <sup>st</sup> looking at the person/boy and recognised that he was on a skateboard.		
		Participants 1 and 3 recognised the skateboard as one of the product designs described; linked its longer life cycle compared to the car (when linked to AOI 'Car'); and it is better for the environment during use and later for recycling (linked to AOI 'Recycle/Reuse').	Participant 2 compared the skateboard and the car in term of the distance and energy used to travel.	Participants 1 and 3 recognised the skateboard as one of the product designs described; linked its longer life cycle compared to the car (when linked to AOI 'Car'); and it is better for the environment during use and later for recycling (linked to AOI 'Recycle/Reuse').
2.		All 3 participants recognised this AOI as a production place; where all the raw materials, disassembly and recycle/reuse of the materials took place (when linked to AOI 'Raw Materials'; 'Disassembly'; 'Recycle/Reuse').		
		All 3 participants linked these AOIs to the design and production of better resources for the products' useful lives or their life cycles.		
3.		Participants 1 and 3 recognised this AOI as a design centre/school.	Participant 2 recognised this AOI as a modern building and implying future direction/strategy for renewable materials or energy.	Participants 1 and 3 recognised the AOI as a design centre/school.
4.		All 3 participants recognised that the 2 main AOIs provide the message about the life cycle of the 2 products; and renewable/reusable materials (when linked to the AOI 'Raw Materials').		
5.			Participants 2 and 3 linked these AOIs as a message concerning the source of reusable materials, fuels or energy efficiency.	

Table 5. Sequence of key connections in the scanpaths for visual-A (3 participants)

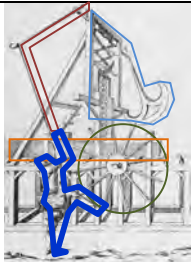
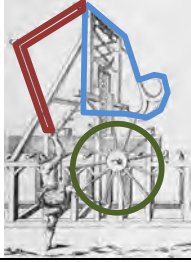
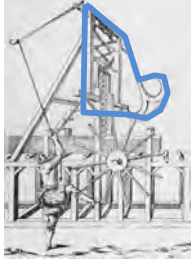
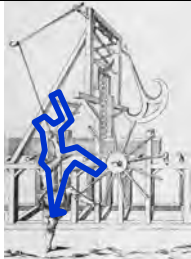
No.	AOI	Understood/interpreted message		
		Participant-1	Participant-2	Participant-3
1.		All 3 participants comprehended that the operator (human) is pulling something to operate the machine, and then pushing the wheel with his leg to move the wood on the conveyor belt.		
2.		All 3 participants recognised that these 3 AOIs are the basic elements/tools for the machine.		
3.		All 3 participants recognised that the elements/tools at this AOI would be moving up-and-down when the operator pulled the handle.		
				Participant-3 recognised this AOI contained a saw to cut the wood when it moves up-and-down.
4.		All 3 participants were comparing the human and the whole machine while being asked what needed to be considered if they were to build the machine. They were agreed on what the size of the machine must be in relation to the size of the human.		

Table 6. Sequence of key connections in the scanpaths for visual-B (3 participants)


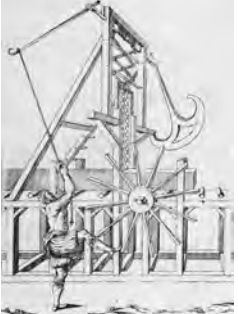

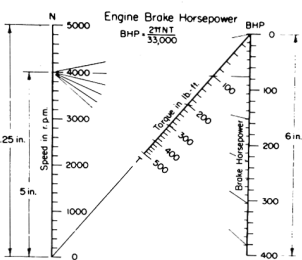
Pair	21th Century Visual Tools	16th Century Visual Tools
1	(A) 	(B) 
Participant (P)	<b>Responses</b>	
	P1	<i>Both have human; both shown via 3D drawing; both tell a story or action about process and function or operation (60 sec).</i>
	P2	<i>Both show technology in time 1) with high-tech and 2) manual-tech (65 sec).</i>
	P3	<i>Both are diagrammatic representations, employed perspective; both use human figures to demonstrate the proportions; giving a perspective of the content (100 sec).</i>
	P4	<i>Both show the process of producing something or showing a physical transformation of something (28 sec).</i>
P5	<i>Both are diagrammatic drawings that have humans involved, showing some hand-on and describing an overall process (66 sec).</i>	
2	(C) 	(D) 
Participant (P)	<b>Responses</b>	
	P1	<i>Both are the means of measures or comparison between products; both can plot points to figure out something 1) to see its efficiency and 2) of some data for calculating size; both like a graph (34 sec).</i>
	P2	<i>Both give a clear form of matrices with precise scales 1) colour legend with criteria/elements and 2) numbers (115 sec).</i>
	P3	<i>Both are graphics with scales 1) with text element/label as scales and 2) quantified matrix (53 sec).</i>
	P4	<i>Both are tools to make measure of a product or engine; both have measurements 1) by descriptions 2) by numbers (20 sec).</i>
P5	<i>Both diagrams are representing ideals of something through drawing points or lines to find out information (27 sec).</i>	

Table 7. Verbal protocol for the comparison of 3 pairs of visuals (5 participants)


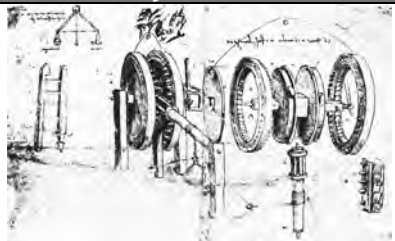
Pair	21st Century Visual Tools	16th Century Visual Tools
3	(E) 	(F) 
<b>Responses</b>		
Participant (P)	P1	<i>Both are informative illustrations, explaining how things work; how things being put together (28 sec).</i>
	P2	<i>Both are for assembly of products; provide details and criteria (56 sec).</i>
	P3	<i>Both communicate through diagrams, which illustrate forms and how to build an objects; and how the object would works; provide different views/sections about the objects; show the purpose; show the dynamic and function; ultimately, about how to build and the design of product (112 sec).</i>
	P4	<i>Both are visuals to make us see the truth of making something 1) kites and 2) a mechanism to carry weight; Both provide details just that 1) with theory, details and measurements and 2) precise visual details on how it works just without measurements (46 sec).</i>
	P5	<i>Both tell us how to make something; giving lots of details on how they work (48 sec).</i>

Table 7. (continued)

**The comparison of the similarities for pair-1 (visuals A & B)**

The interpretation at this section is based on Tables 5, 6 and 7. Tables 5 and 6 illustrate the messages perceived by the 3 participants, either from what they have understood or interpreted, in relation to the AOI from their scanpaths. Table 7 shows the 5 participants' understanding/interpretation of the messages with the time of the descriptions within the protocol. The data were drawn from the protocol transcripts.

All 5 respondents (3 with full records of visual recordings and analyses, and protocol transcripts; 2 with only raw visual sources and protocol transcripts) agreed that both visuals tell the story of product(s) and their associated technologies or processes (Table 7). Three of them (non-engineering background) emphasised that both visuals use human depictions as a reference to provide messages about the product(s) depicted, e.g. reference to some sort of dimensions, processes involved and/or functions of the products in relation to the environment or technology around them (Tables 5 – 7). Overall, the representations were reported as providing perspectives of messages or stories relating to the content of the visual information; where the human becomes the centre point for the readers to connect and explore relationships to the surrounding AOI. Thus, the human figure provides a starting or reference point for the readers.

**Pair-2 (visuals C & D) results and their links to VCT principles**

An in-depth visual analysis (as of what the viewers actually 'see') for 3 respondents as in pair-1 analysis has not yet been completed. However, this section will report the findings of 5 participants, based on their protocol transcripts (as of what they 'said' and 'understood') of visuals C

and D (refer to Tables 1 or 2), and simple observation from the raw data of eye-tracking. Similar and consistent patterns of searching for a form of matrix were demonstrated amongst the 5 respondents.

**Pair-2: Initial findings for visual-C**

An initial observation demonstrated that all 5 participants read the sub-title from the very top, then focused on the web (coloured rings/circles), following by reading the other 6 sub-titles and text around the web that has added axis lines that point to the sub-titles (lines in Figure 5). Subsequently, these 5 participants focused back to the centre of the web and the scanning move outwards (as indicated by the dashed arrow in Figure 5), in between there were several fixations (dots in Figure 5) at different colours of the rings. This observation will be further analysed using the same strategy as in the analysis of pair-1, which will be drawing out the detailed scanpath patterns from the raw eye-tracking data.

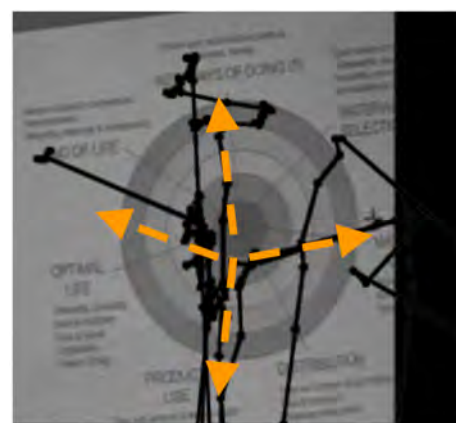


Figure 5. Eye-Tracking Scanpath Visual-C (P3)

**Pair-2: Initial findings for visual-D**

An early visual analysis showed that all 5 participants clearly recognised the 3 scales in the diagram of Visual-D (Table 7), meaning that they recognised the 'unity of form' of the diagram. However, their reading paths seemed slightly differently. One participant scanned more on the left vertical scale, and less on the centre diagonal and right vertical scales; 3 participants paid even attention to all the 3 scales; 1 participant focused on the left vertical and central diagonal scales, but not the right. Subsequently, 3 participants scanned the diagram in a smooth sequence that has fixations on the left, centre, then to the right scale in a diagonal direction (from top left to lower right, shown by the dashed arrow in Figure 6). But, the other 2 participants were still scanning in a scattered or unsystematic manner. The understanding of the diagram in terms of recognising the 'function' with or without language guide was:

1. Two of the 3 female participants could not recognise immediately the 'function' pattern of the scales without the language guide;
2. One of the 3 females and both male participants could read the function aspect immediately without the language guide (overall, 3 out of the 5 participants' understood immediately the key 'unity of form' and its 'function').

**The comparison of the similarities for pair-2 (Visuals C & D)**

The early observation of the 5 respondents revealed that they all were able to identify the pair-2 visuals as forms of tool or matrix for calculating and making precise decisions for something (Table 7).

**Pair-3 (visuals E & F) results and their links to VCT principles**

This section also reports the initial findings of 5 participants, based on their protocol transcripts of the visuals E and F, and the direct observation of the raw eye-tracking data. A similar and consistent pattern of looking for a whole depiction, and then exploded details, followed by enlarged details in both visuals E and F were found for all 5 respondents.

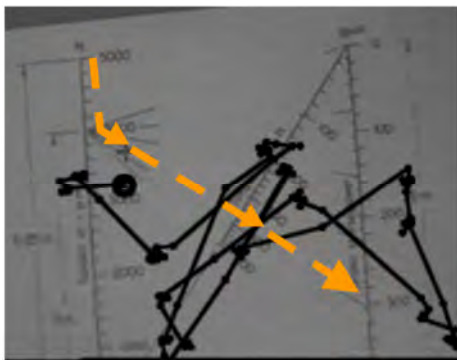


Figure 6. Eye-Tracking Scanpath Visual-D (P3)



**Pair-3: Initial findings for visual-E**

An early analysis reveals that all 5 participants were scanning from the red poster, then moved to the blue poster. In the blue poster they viewed from top left section, and then to top right, lower left and finally to lower right (highlighted by dashed arrow in Figure 7). The red poster is about the overall concept and basic structures of kites; and the blue poster is about technological and detailed information regarding kite-forces, kite-balancing, kite-centre-of-gravity, and kite-troubleshooting. All descriptions from the 5 participants were very similar: visuals that provide detailed information about kite-making (an overall or obvious message of these posters). Also, they were able to describe detailed information from each section.

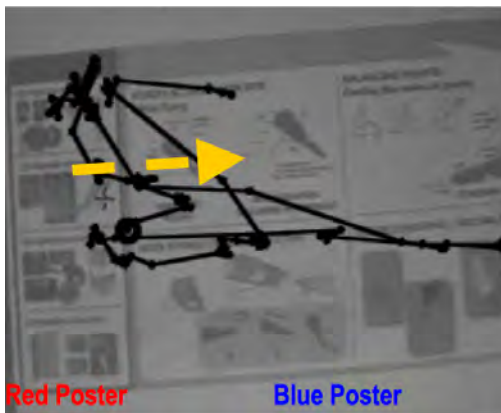


Figure 7. Eye-Tracking Scanpath Visual-E (P1)

**Pair-3: Initial findings for visual-F**

An early analysis reveals that all 5 participants were scanning from left to right (indicated by dashed arrow in Figure 8), which were from an overall image of a device to detailed parts and enlarged details of the device.

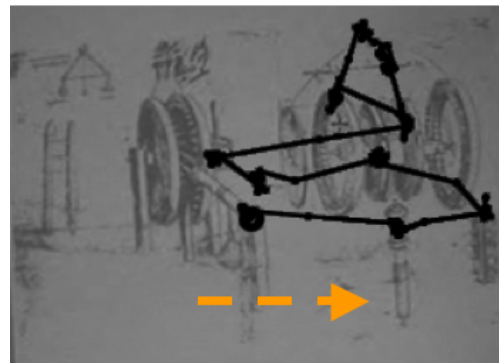


Figure 8. Eye-tracking scanpath for visual-F (P2)

**The comparison of the similarities for pair-3 (visuals E & F)**

The early observation of 5 respondents revealed that they were all able to identify the pair-3 visuals as illustrations of technological information, explaining how things work or are put together; providing various details of product or product-making (Table 7).

## Discussion

The eye-tracking findings showed that what was said by the participants was consistent with their scanning of the visuals and what they understood from them (Tables 3 – 7). Key emerging principles (KEP) of visual communication of technology (VCT) seem identifiable from the scanning paths' patterns and the indicated behaviours (as shown by the analyses based on Tables 3 – 7), and this could confirm the VCT principles derived from the literature review. The eye-tracking investigation revealed that:

- **Pair-1:** The participants' reading/eye-scanning behaviours were quite similar (Tables 4, 5 & 6), which were to '*compare*' the interaction between humans and the surrounding technological information to reveal connections and the '*relationship*' of the extensive messages about the products, processes, proportions, and materials. This supports the hypothesis within the first KEP of VCT (1<sup>st</sup> KEP of VCT = COMPARE > RELATIONSHIP).
- **Pair-2:** The early observation of these 5 respondents' scanning patterns from the raw data and the protocol transcripts demonstrated that the viewers were trying to understand the '*form meaning*' (or comprehending the form unity) within the coloured web and the text; later to search for '*functionality*' of the web (eg what the coloured rings represent). All respondents described that they were able to understand the coloured rings' function as a form of matrix/scheme, accentuating different levels of good or bad in order to support sustainable design analysis.
- **Pair-2:** A significant similarity in terms of scanning patterns of the matrices in the 2 diagrams (Visuals C & D) was recognised, even though one uses a colour scale and the other uses number scales. In terms of functionality, there was no doubt that the additional language guide provided better comprehension of the form. The circular scale was viewed from the centre to the outer ring; whereas, the linear scale was viewed from top left to lower right. These scanning patterns were the same for all 5 participants (although 2 of them took a longer time to capture this scanning pattern). The current analysis indicates that the viewers were trying to understand the '*form meaning*' (or comprehending the form unity); and later search for '*functionality*'. This matches the 2<sup>nd</sup> KEP of VCT (FORM > FUNCTION).
- **Pair-3:** The pattern of the 5 participants' reading of visual information could be interpreted as if they were searching for '*precision*' of details after knowing the whole concept or idea of a thing, so as to understand the '*truth*' or accuracy of information, and this suggests support for the 3<sup>rd</sup> KEP of VCT (PRECISE > TRUTH). However further detailed analysis is needed.

## Conclusion

- The eye-tracking pilot experiment showed that the data collection methodology works, and provided intriguing quantitative and qualitative data for analysis.
- The initial eye-tracking results provided significant patterns that were relevant to the validation of the key emerging VCT principles established from the literature review.
- The experimental results also provided some further explanation concerning the evidence of some effective impacts of visual communication concluded in the earlier case studies (Storer, 2005; Beh & Norman, 2009) for the 3 current visual samples and the 3 historical examples of good practice in the VCT.
- The statistical data needs further analysis in order to establish whether it can fully support what has been asserted and found in literature, evidence obtained from the case studies, and the visual analysis from the eye-tracking experiment.

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## Differences in the epistemological beliefs of postgraduate pre-service teachers.

Raymond Lynch

### Abstract

*This paper evaluates the epistemological beliefs (in relation to assessment) of 18 Postgraduate Certificate in Education (PGCE) students specialising in technology education at the University of Limerick. The study focused on student responses to a technical graphics assignment undertaken as part of their course. This assignment required students to develop a suitable assessment model for discrete topics from the Design and Communication Graphics syllabus. The epistemological beliefs of many of the postgraduate students in this study often reflected a summative and dualistic approach to assessment. Discrepancies were also shown to exist between students' perceptions of apposite pedagogy and their epistemological positions. Findings from this initial study highlight important questions surrounding the epistemological beliefs of pre-service technology teachers and the impact of these positions on teacher pedagogy.*

### Introduction

The individual beliefs students hold about knowledge and knowing, referred to by Hofer (2001) as "personal epistemology", have been shown to influence learning in many ways throughout both second and third level education. Contemporary research has established that epistemological beliefs can influence students' reasoning (Sinatra, Southerland et al. 2003), judgements and levels of motivation (Hofer 1999; Paulsen and Feldman 1999). This inevitably has implications for teacher education and PGCE courses as the personal epistemological beliefs of educators have also been shown to further influence their students' learning outcomes (Hofer 2000). As a result the area of personal epistemological development and beliefs has received growing attention amongst educators and psychologists. Despite the salient position of epistemological development within educational psychology, there exists a dearth in research relating to students' personal epistemological beliefs in the area of technology education.

## Background

The majority of work on epistemological beliefs and development can be traced back to two longitudinal studies by William Perry (1970) that began in the early 1950s at Harvard. Perry's work complemented emerging research in the areas of cognitive and moral development. In particular Perry's work built on that of Piaget (1950) who used the term 'genetic epistemology' to describe his theory of cognitive development. Piaget's research addressed the nature of knowledge and knowledge acquisition, resulting in a proposed developmental stage theory. The findings of Piaget's research are particularly pertinent within technical graphics education as they propose that it is not until an individual reaches the 'formal operational' stage that they can develop and manipulate conceptual objects (Piaget 1950), a skill vital in solving most graphical communication exercises. Further building on Piaget's research into intellectual development, theories on moral judgement and development soon began to emerge (Kohlberg 1969; Kohlberg 1971; Gilligan 1982). Both areas of research led to advancements in psychometric assessment methods for cognitive development (Goldstein and Hersen 2000). Inspired by the work of Piaget and encouraged by the recent developments in cognitive assessment Perry (1970) attempted to understand how the pluralistic pedagogical strategies and social environments of university impact of students' epistemological development. Perry's research led to a theory of epistemological development in college students.

In order to assess students' epistemological beliefs and to help select students for further interview, Perry developed a quantitative instrument that he called a Check-list of Educational

Values (CLEV) (Moschner, Anschuetz et al. 2008). Many items and statements from the CLEV such as "The best thing about science is that most problems have only one right answer", have since been adopted by more contemporary inventories on epistemological beliefs (Schommer 1990). Perry's research culminated in the development of a scheme of intellectual and ethical development which postulates that there exists an on-going, adaptive reorganisation of positionality amongst students and their epistemological beliefs. Although often erroneously referred to as stages, Perry (1970) designated levels in his scheme as "positions" and not representing a formal developmental process. However Perry's scheme shares much with other Piagetian-type developmental schemes where positions appear to be hierarchical and change is brought about in response to cognitive disequilibrium (Hofer and Pintrich 1997; West 2004). Although initially consisting of nine positions Perry's scheme of moral and intellectual development can typically be understood to consist of four successive categories (Knefelkamp and Slepitz 1976; Moore 1994; Moore 2002). The basic scheme is as follows:

*Dualism* – this is characterised by dualistic, absolute, right-and-wrong views of the world where students believe that authorities know the truth and convey this, in the process separating right from wrong. Here authorities are often viewed as omniscient beings.

*Multiplicity* – this represents a modification of dualism where students believe that information is neither absolute nor externally mandated by authorities and that everyone is entitled to his/her own opinion. This change in students' beliefs can often result from two authorities disagreeing on what is correct or true.

*Relativism* – this represents a critical turning point in students' beliefs away from dualism towards a perception of self as an active maker of meaning. Here opinions are based on context and evidence, resulting in a necessity to choose and affirm one's own views. As such, knowledge is contextual and predicated on past experiences. This position requires the use of intellect to shift from context to context, applying 'rules of adequacy' to information, concepts, perspectives, and judgements.

*Commitment within relativism* – this focuses on responsibility, engagement, and one's commitment to their beliefs when faced with the uncertainty of what Perry called the 'relativistic world'. Here individuals make and affirm commitments to values, relationships, and personal identity.

Since Perry's work many have begun to look at assessing how students' epistemological beliefs link to other areas such as cognition, reasoning and motivation (King and Kitchener 1994; Kuhn 2000; Hofer 2004; Kruger and Cross 2006). This paper examines the epistemological beliefs of post-graduate pre-service teachers of technology subjects and the impact this has on their respective pedagogy.

## Methods

As part of a graduate diploma course for technology education teachers, students were tasked with performing a topic analysis of discrete Technical Graphics topics which were specific to each student. This assignment required students to develop a suitable teaching and assessment strategy for their given topic to advance pupil learning, levels of engagement and motivation, as well as promoting assessment for learning. To

help structure the assignment it was further broken down into key requirements. First students were required to develop a teaching folder outlining their approach to teaching the given topic, including appropriate resources, models and teaching aids where applicable. Next they were required to develop a series of motivational questions to communicate the principles and concepts of the given topic, as well as providing a rationale for covering the topic. Finally, central to the assignment was the requirement to develop a suitable assessment strategy to determine the success of their proposed pedagogical design. It was also highlighted that this assessment strategy should be formative and not summative in nature, with the focus on assessment for learning and not accreditation. Students were given nine weeks to complete the assignment from receiving their specific topic, to allow time to research and investigate the key principles and develop appropriate assessment strategies.

For the purpose of this paper students' work was examined for qualitative evidence of their espoused epistemological beliefs, with particular focus on the assessment strategy they developed as part of their solution to this assignment. In order to ensure authenticity in students' responses to the given assignment they were not prior informed of the objectives of this study, as underlined by Silverman (1993), "authenticity rather than reliability is often the issue in qualitative research" (p. 10). A development from Perry's (1970) evidence of epistemological beliefs was used to determine students' epistemological position as shown in Table 1. Similar evidence of positions is also echoed in the Schommer Epistemological Questionnaire (Schommer 1998).



	<b>Dualism</b>	<b>Multiplicity</b>	<b>Relativism</b>	<b>Commitment within Relativism</b>
<b>Evidence of Position</b>	Focus of the teaching folder is on conveying information or knowledge and the role of assessment is to demonstrate that pupils' have learned the correct answer.	Focus of the teaching folder is on how pupils learn and varying the stimuli and approaches. The assessment strategies allow for multiple right answers and require pupils' personal input.	Focus of the teaching folder is on encouraging students to think for themselves by using supportive evidence. The role of assessment is to determine if students can develop and adapt prior knowledge structures to solve new problems from the "relativistic world".	Focus of the teaching folder is on encouraging pupils to apply personal rules and beliefs to concepts, perspectives and judgements. The role of assessment is to encourage pupil judgements and decision making by applying their personal understanding of concepts and principles.

Table 1. Evidence of students' epistemological beliefs and positions

Discourse analysis of students' responses to this assignment was conducted to investigate trends of dualism, multiplicity, relativism, and/or commitment within relativism emerging from students' reported assessment strategies. Given the qualitative nature of this study, an ethogenic approach was taken as advocated by Harré (1978). In keeping with the process proposed by Brown and Sime (2009) the resulting research data were evaluated in accordance with the control procedures outlined in Table 1. Initially the qualitative data were codified into two groups (lower and higher order epistemic values) in respect of the overall discursive patterns emerging. For this initial stage of the analysis, codes were assigned based on evidence of (or lack thereof) students' assessment strategy promoting the perception of 'self as an

active maker of meaning' i.e. moving beyond dualism and towards relativism. Then axial coding was applied to further review the data for emergent themes and assess for similarities in respect of the control procedures outlined in Table 1. For example teaching and assessment strategies that promoted polarised perceptions of knowledge (right or wrong) in which students are awarded marks only upon the correct completion of discrete elements of graphical exercises were coded as dualism. Conversely, teaching and assessment strategies that promoted problem solving skills through the adaptation and application of prior knowledge structures, in respect of individual student experiences, were viewed as echoing epistemic values of relativism.

The participating cohort consisted of 18 postgraduate students, 17 male and 1 female student. All students had previous knowledge of educational psychology and developmental theories through their teacher education course. During the completion of this assignment students were also simultaneously undertaking a period of teaching practice where they spent one day each week teaching in various second level schools. The following section presents the results of this initial study with a view to further investigation into this area through a longitudinal study on future PGCE student cohorts' epistemic values.

## Results

From analysis of the students' work it is clear that the majority of their assessment strategies reflected positions of either *Dualism* or *Multiplicity*, with few students presenting a position of *Relativism* and none of the students' approaches to assessment displayed a *Commitment within Relativism*. The breakdown of students' epistemological positions as evident from discourse analysis of their respective assessment strategies is shown in Table 2.

	Dualism	Multiplicity	Relativism	Commitment within Relativism
Student 1		X		
Student 2	X			
Student 3	X			
Student 4	X			
Student 5			X	
Student 6	X			
Student 7		X		
Student 8	X			
Student 9	X			
Student 10		X		
Student 11		X		
Student 12		X		
Student 13			X	
Student 14	X			
Student 15		X		
Student 16	X			
Student 17	X			
Student 18			X	

Table 2. Students' epistemological positions as evident in their assessment strategy

## Lynch

Qualitative examples from students' assessment strategies that reflected an epistemological position of dualism include:

On completion of the topic students will sit an exam with sections covering the theory of the topic and graphical skills. The assessment exam will use problems with a similar style to previous exam type questions and will be presented to them on the last day of covering the topic. (Student 14)

At the end of the topic a summative assessment will be conducted in order to gauge students understanding of the subject matter. A summative test at the end of the subject with similar questions to those covered in class will further reinforce students understanding of the topic. (Student 8)

The above examples reflect the traditional and dualistic assessment strategies for nine of the students involved in this technical graphics module. For these students their approach to assessment was largely summative, focusing on their pupils' ability to solve similar questions to those covered in the classroom and reproduce information provided by the teacher. This was also reflected in students' grading criteria for their assessment with many developing marking schemes which awarded individual marks for getting specific elements of a question 'correct', irrespective of a pupil's approach or level of cognition.

The following examples represent approaches to assessment which reflect a position of multiplicity in students' epistemological beliefs:

I have also offered a third question that is open. It is intended that this question could be worked out collaboratively in class or individually by a pupil as a mini project. Marking schemes for these questions would be agreed between the teacher and the pupils. (Student 7)

The assessment will allow students to choose which ever method they want which promotes student taking their own initiative and choosing a method that they either like or have a preference for. (Student 11)

The assessment approach of students 7 and 11 allowed for a certain level of personal input, as well as for having multiple right answers or solutions. Similar approaches to assessment were adopted by 5 other students from the participating cohort.

Finally the following examples highlight some of the assessment strategies deemed to reflect an epistemological position of relativism, exhibited by three students within the participating cohort:

Students will not have met with the need for additional parts that will be required to finish the drawing accurately. It is intended that this further advancement will require the students to think laterally and solve the problem before them in a logical manner, applying the techniques learned for planning an assembly & practical problem solving from earlier lessons. (Student 18)

The main part of the assessment will come in the form of a presentation. The class will be broken up into 4 groups of mixed ability and each group will have to come up with a topic from conics to talk about for 10

minutes. Students can use any medium they wish to show their understanding of their chosen topic. (Student 5)

### Discussion

Despite the requirement for students' assessment strategy to be formative in nature and to focus on assessment for learning, as outlined in the brief, the majority of students relied on summative approaches to assessment with the focus on assessment for accreditation. The assessment strategies presented primarily centred on dualistic and traditional style questions, with students' rationales for the inclusion of their respective topics directed toward successful completion of the Leaving Certificate examination (the principal component for the allocation of university places under the Irish matriculation system). This was highlighted in the following students' comments:

Students will have covered many different types of questions in class but the key objective for students is their ability to answer a leaving certificate style question. (Student 15)

This topic is examined both at higher-level & ordinary level for the Leaving Certificate Section C Question 1. It is important to start this topic by revisiting skew lines [*Topic for L.C.*] as the boreholes may be treated as skew lines for the purposes of answering parts of this question in the exam. (Student 17)

The findings of this paper suggest that despite the pluralistic pedagogy and learning environment offered to students throughout their university course, many continue to refer back to the Leaving

Certificate examination and past exam papers to inform their teaching and assessment strategies. During an informal class discussion as part of post assignment feedback to the students, the reasons for this were alluded to by some students. For example, one student highlighted a personal preference for design driven assignments, however when asked to develop an assessment for second level students a traditional summative examination was submitted in its place. The rationale provided for adopting this approach to assessment (even with personal experience and understanding of the benefits of design driven assessment) indicated that time constraints and requirements of the Leaving Certificate examination prevent the use of a similar approach to assessment at second level. The disposition of this student can be explained by a concept often referred to as Cognitive dissonance (Harmon-Jones and Mills 1999; Stone and Cooper 2001; Gawronski and Strack 2004). Here the student presents a level of cognitive recognition of the benefits provided by design driven assessment yet chooses to ignore this in favour of alternative assessment strategies as a result of perceived external pressures. Greater levels of dissonance between pedagogical beliefs and practice have also previously been reported for design driven, creative subjects with students afraid to express certain design ideas for fear of "getting it wrong" (Stark 2009).

Students also made reference to the teaching and assessment strategies they experienced at second level as having a significant influence on their pedagogy in a process referred to by Lortie (1975) as 'apprenticeship of observation'. Given that the teaching and learning experiences of the participating cohort proved successful in preparing them for the Leaving

Certificate examination, many find it hard to accept and adapt to alternative approaches to learning (Lortie 1975; Grossman 1991).

Findings from this initial study suggest that the influence of both 'cognitive dissonance' and 'apprenticeship of observation' has resulted in many of the postgraduate students in this study presenting epistemological positions of dualism, promoting summative approaches to assessment with definite solutions/answers. However, Black and William (1998) highlight that in order for assessment to promote 'mastery learning' (Bloom 1971) it must remain formative in nature and encourage self-assessment and reflection. Therefore, dualistic approaches to assessment are not favourable within teacher education courses which aim to promote 'deep' learning and critical thinking skills, as highlighted by Entwistle (2000). The assessment of graphical communication exercises must support student learning by encouraging self-reflection, "assessment changes might be expected to enhance learning if they help students to develop reflective habits of mind" (Black and William 1998, p24). Consequently, the development of apposite assessment strategies for technical graphics tasks demands a shift in epistemic values beyond basic dualism. Findings from this study also suggest that for many of the technology education students involved, a link exists between their epistemological beliefs and the pedagogical and assessment strategies employed. However, it is to be noted that this was a small study designed to take an initial look at 18 PGCE students within a single teacher education course at the University of Limerick. Further studies involving subsequent cohorts and across comparable courses in other institutions are required to expand upon and further

validate these findings. Future research aims include a longitudinal study across subsequent PGCE student cohorts, and would welcome and endeavour to pursue similar collaborative research with other institutions offering related PGCE courses.

### Conclusion

The findings from this study raise questions surrounding apparent discrepancies between pre-service teachers' conception of appropriate pedagogy and the espoused epistemic values evident in their assessment strategies. Pre-service technical graphics teachers on this PGCE course rarely presented assessment strategies that reflected a position of relativism. However, is such an emphasis on dualistic approaches to assessment acceptable within technical graphics education? The author would argue that the design driven focus of many contemporary technology education programmes and the recently introduced syllabuses at second level in Ireland (NCCA 2006) places greater prominence on the individual learning experience of the student. This philosophy is central to catering for the diverse teaching and learning requirements of students as advocated by Felder and Brent (2005);

Students have different levels of motivation, different attitudes about teaching and learning, and different responses to specific classroom environments and instructional practices. The more thoroughly instructors understand the differences, the better chance they have of meeting the diverse learning needs of all of their students (Felder and Brent 2005, p57).

Therefore, the successful integration and implementation of a more student centred

approach to technical graphics education demands assessment strategies that move beyond basic dualism, where knowledge is presented as either right or wrong irrespective of the individual experiences of the students. Findings from this initial study also suggest that the effects of 'cognitive dissonance' and 'apprenticeship of observation' are influencing the assessment strategies employed by participants. However, this again poses the question whether or not participants were conditioned into adopting this approach due to a lack of experience

setting assessment criteria for graphical communication exercises based around relativism? If so, would encouraging students to develop assessment strategies for technical graphics throughout their PGCE course accordingly promote students' epistemological development? Findings from this initial study suggest a link between students' epistemological beliefs and pedagogy however a significant dearth in research exists regarding the influence of initial teacher education on pre-service teachers' epistemological development.

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## Ken Baynes

*Visiting Professor*

*Design Education Research Group  
Loughborough Design School  
Loughborough University*



Ken Baynes was born at Eynsford in Kent on 10<sup>th</sup> April 1934. Privately educated he studied stained glass at Bideford School of Art and the Royal College of Art where, in 1959, he became editor of the college magazine, *Ark*.

While editing *Ark* his professional interest moved to the media, particularly magazines and exhibitions. On leaving the RCA he became assistant editor of the international graphics journal, *Graphis* based in Zurich. When he returned to London in 1963 he established his own practice as a writer, editor and designer.

Although trained as an artist/craftsman, Ken has spent his professional life working as a researcher, designer, educator and writer. At the centre of his work has been two main themes: the use of exhibitions as a medium for entertainment and education; and the attempt to develop better strategies for teaching and learning about art and design in Primary and Secondary Schools. Over the past decade he has campaigned for 'practical' education in a number of related fields including food and cooking; drawing; and gardening. A continuing research interest focuses on the insights offered to the arts and design by new developments in cognitive science and digital media.

Ken is a Visiting Professor at Loughborough Design School; co-founder of the Design Dimension Educational Trust and Editor of *Cook School*, a magazine for teachers published by the Focus on Food Campaign. He has played a leading role

in the publication programme of the Campaign for Drawing. With his wife Krysia, he is a partner in Brochocka Baynes specializing in art and design exhibitions and events aimed at schools and family groups. He has written reports and conducted research for the King's Fund and with Krysia Brochocka for the Ove Arup Foundation, The Design Council, Scottish Natural Heritage, the Craft's Council and Loughborough University. In 2009/10 Ken ran a Seminar Series called *Models of change: the impact of 'designerly thinking' on people's lives and the environment* within the Design Education Research Group at Loughborough Design School. These were published as part of the Orange Series and can be freely downloaded from Loughborough University's Institutional Repository:

<https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/1686>

Over the years, Ken contributed regularly to *Design* magazine, the *Times Literary Supplement* and *Architectural Review*. He was the scriptwriter and presenter for Channel 4's *Design Matters* series where he was involved in creating 27 programmes dealing with every aspect of design. For a number of years he worked with the Welsh Arts Council pioneering a series of large exhibitions intended to relate art to the life experiences of 'ordinary' people.

## Cheng-Siew Beh

*Research Student*

*Design Education Research Group  
Loughborough Design School  
Loughborough University*



Cheng-Siew Beh obtained her BSc in Graphic Design in 1997 from Northeastern University, USA; and Master of Technical Education in 1999 from University Technology Malaysia. She is currently in her third and final year of MPhil/PhD research degree in the Design School at Loughborough University.

Cheng-Siew previously had 4 years lecturing experience in the area of Graphic Design at diploma level, and 5 years working in the area of curriculum design and development in Malaysian Polytechnics system. Her lecturing experience includes using both common spoken-languages for normal students; and sign-language for special needs (deaf and dumb) students. She also acted as an academic advisor for the special needs group, and was actively involved in academic and pastoral care throughout the 4 years. She joined the Ministry of Higher Education Malaysia, and later led the curriculum design and development team, revising and developing 2-year certificate (outcome- and work-based) programmes and 3-year diploma (project-based) programmes for Malaysian Community Colleges and Polytechnics. The involved programmes include Art & Craft for Batik and Woodcraft; Graphic, Fashion and Industrial Design; Creative Multimedia for Animation and Video-Film Studies; and Print Media. She was also involved in writing specifications of accommodation for

new developments of institutions, and developing courseware for e-learning used in those institutions.

From this background, Cheng-Siew is now seeking to establish principles behind the visual communication of technology (VCT). Her research investigates links between the learning of technology through visual communication and associated creativity and innovation in industrial and engineering design. So far, empirical evidence has been gathered concerning the validation of the key emerging principles of VCT, established from a literature review of good practice. Her work has featured in academic publications at conferences and workshops.

## Xenia Danos

*Research student*

*Design Education Research Group  
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Xenia Danos gained her BA Honours Degree in Design and Technology in 2004 and a PGCE for teaching in secondary schools in 2005 from Middlesex University. She is currently in her third and final year of an MPhil/PhD research degree in the Department of Design and Technology at Loughborough University.

Previously she had 3 years experience as a secondary school teacher. The subjects she covered included product design, CAD and engineering at AS/A2 level, graphic products at GCSE level for which she wrote the scheme of work for the department; resistant materials, structures, systems and controls, textiles, food technology and art at KS3 level. She also acted as a form tutor to the upper sixth form throughout the 3 years and was actively involved in the academic and pastoral care. As an active member of the school community, she ran after school classes for her GCSE groups, taught Greek language classes and held individual sessions for the less and more able students. She was also involved with the Duke of Edinburgh club and excursions run by the PE department.

With this wide range of interests, Xenia is now working on establishing principles behind visual communication and students' learning, focusing her study on secondary school level. Her research examines the graphicacy (or visual literacy) within secondary school curriculum provision and investigates links between the skills required to read and create visual images (such as maps, diagrams, symbols and charts). During her research the cross curricular importance of graphicacy has become evident, but for the PhD research programme, it was decided to focus on acquiring outbound (creative) graphicacy competences. Throughout the 3 years, she has established collaborations with a number of schools and universities in the UK, the USA, Cyprus and Sweden. Her work has featured in numerous academic publications, conferences and workshops.

## Dr Ronan Dunbar

*Lecturer*

*Department of Mechanical Engineering  
Athlone Institute of Technology*



Ronan Dunbar completed his PhD in technology education research in May 2010. The study was a longitudinal cohort analysis of the preferential learning styles of the student technology teachers at the University of Limerick. A review of the impact of teaching strategies and varied learning environments on the learning styles of the students during their undergraduate teacher education formed the basis of the doctorate study.

Ronan was an associate researcher for the Technology Subject Support Service (T4) during the intensive phase of the Design and Communication Graphics in-service delivered to Irish second level teachers in preparation for the initiation of the new subject in September 2009. This role included the design and delivery of resources to align with the new 'integrated approach' of the graphics subject.

Ronan's current role is as a Lecturer within the Mechanical Engineering Department at Athlone Institute of Technology.

## Michelle Fava

*Research Student*

*Drawing Research Group  
School of the Arts  
Loughborough University*



Michelle began PhD study at Loughborough University School of the Arts in 2010. Previously she taught drawing, sculpture and contextual studies in Further and Higher Education.

Her previous research has been concerned with curriculum development and teaching methods for drawing and contextual studies. Michelle's current research engages with drawing pedagogy and psychology of attention. She is an active member of Loughborough University Drawing Research Group and the Drawing Research Network, while also exploring experimental approaches to interdisciplinary collaboration through the Satellite Group, a Loughborough based postgraduate research community.

Michelle's PhD research considers the educational relevance of contemporary theories of attention and cognitive studies of drawing. Empirical observation of artists' drawing behaviour is used to bridge these disciplines, by considering the attentional strategies artists employ in order to draw from observation. Video footage and verbal accounts of drawing inform a cognitive analysis, making a practical exploration of cognitive theories of visual attention and their relevance to contemporary drawing pedagogy. Computational and embodied cognitive paradigms are considered, both being informed by neuroscientific findings, which

contribute to clarifying the nature and limits of visual attention, and its role in learning.

Her paper discusses the role and potential benefits of observational drawing practice through an interdisciplinary perspective. It examines the issue of assessment, and the reasons for valuing the process as well as product of drawing activity. Like many of the papers in this collection, it identifies a need for reform, inviting creative responses to the questions of how to develop curricula, and approaches to assessment, in response to the needs of contemporary art and design students.

## Dr Seamus Gordon

*Lecturer*

*Technology Education Research Group  
Department of Design and Manufacturing  
Technology  
University of Limerick*



Seamus joined the University of Limerick in 1993 having spent 10 years working in the Irish manufacturing and education sectors. During this time he worked as a manufacturing engineer, teacher at second level and as an engineering consultant in the area of computer-aided design and manufacture. He obtained his B.Tech (ed) in 1987, M.Tech. in 1991 and PhD in 2002.

Having joined UL primarily to teach on the mechanical and manufacturing engineering programmes, he found himself being increasingly involved with the technology teacher education programmes over the subsequent years. He became course director in 2003 for the B.Tech (ed) M&ET programme which is the sole national provider of graduate teachers for two of the suite of technology subjects offered in Irish Schools. At present he teaches design and automation topics to year two and year three students on this programme.

He is the chair of the Course Board for this programme and sits on numerous other university committees.

With the recent review of the technology subjects on the Irish curriculum he has provided extensive consultancy to the Department of Education and skills in the development of CPD for practicing teachers as well as the design of the assessment instruments for the new subjects with the State Examinations Commission. He provides consultancy on an ongoing basis to the Irish Teaching Council.

To date, Seamus has supervised 10 Masters students and 4 PhDs across a range of topics, both in engineering and education.

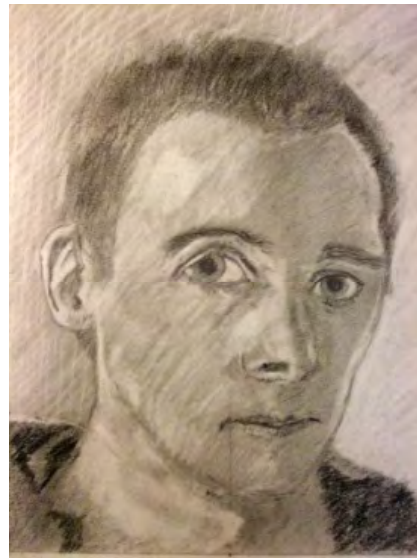
## Dr Diarmaid Lane

*Research student*

*Technology Education Research Group  
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Technology  
University of Limerick*

Diarmaid Lane has recently successfully defended his Ph.D. at the University of Limerick and will graduate in August 2011. Previous to undertaking his Ph.D. research, he completed a four year craft based apprenticeship as a “*Metal Fabricator*” and then went on to complete his degree in Technology Teacher Education in 2008. Having achieved a first class honours degree Diarmaid was employed in the University of Limerick with responsibility for delivering graphics based modules to undergraduate students of Initial Technology Teacher Education (ITTE).

Since undertaking his research in “*Developing Sketching Expertise within Technology Education*” under the supervision of Dr Niall Seery and Dr Seamus Gordon, Diarmaid has published a number of international peer reviewed journal and conference papers. He has presented his research to international audiences on numerous occasions. He is currently the postgraduate representative on the executive committee of the Technology Education Research Group (TERG) at the University of Limerick. He is also an active member of the Engineering Design Graphics Division (EDGD) of the American Society of Engineering Education (ASEE) and is the current holder of the divisions “*Chairs Award*” for best paper presented at the ASEE Annual Conference in Louisville, Kentucky. In October 2010, Diarmaid was invited to Michigan, U.S.A. to present a



sketching workshop to world leading academics in the area of graphics and visualisation. He has received scholarships to support his research activities in the University and these include the award of “*Advanced Scholar*” in 2008 and the “*William J. Flynn Award*” in 2010.

Diarmaid's PhD. research investigated how sketching ability could be developed in students of technology education so that it could be used as a sense-making, conceptual support tool. Over a three year period, he conducted a number of studies which addressed deficiencies in the research literature. He devised and empirically validated a model of sketching activities which ranged along a continuum from observation to imagination. His research has attracted significant interest in Ireland, USA and the UK.

This paper presents one element of Diarmaid's Ph.D. research methodology. It describes the application of visual and verbal protocols and the subsequent examination of students sketching skill, behaviour and cognition prior and subsequent to participating in specially designed sketching activities.



## Dr Raymond Lynch

*Lecturer*

*Technology Education Research Group  
Department of Design and Manufacturing  
Technology  
University of Limerick*



Raymond is a lecturer in the Department of design and Manufacturing Technology at the University of Limerick. He is currently responsible for the delivery of Design and Communication Graphics, as well as Process Technology modules to pre-service technology teachers. His research interests include student interests, self-efficacy, and metacognition, as well as complimentary teaching and learning strategies such as problem and project based learning (PBL). Ray is currently engaged in the development and implementation of new undergraduate modules for technology education students which include significant PBL and peer feedback elements and are guided by recent research endeavours.

Ray also completed his PhD studies at the University of Limerick. His PhD research focused on student interests and their relationship with undergraduate performance and attrition rates. This research demonstrated that within the area of technology education, students' interests were a stronger predictor of undergraduate performance than prior academic results. More importantly, this research highlighted that presage activities are responsible for the construction of a series of perceptual schemata that have a direct influence on undergraduate student learning. Consequently Ray is currently conducting research into two

complimentary areas; first he is looking at how such presage variables develop with particular focus on the perceived link between self-efficacy and the crystallisation of interests, and second he is looking at how such variables can influence teaching and learning strategies at third level.

His paper evaluates an alternative variable, that of students' epistemological beliefs, and their relationship with the espoused teaching and learning strategies of 18 PGCE students. The findings from this paper raise questions surrounding apparent discrepancies between pre-service teachers' conception of appropriate pedagogy and the epistemic values evident in the assessment strategies they adopted.

## Dr Oliver McGarr

*Lecturer*

*Technology Education Research Group  
Department of Education and Professional  
Studies  
University of Limerick*



Dr Oliver McGarr is a lecturer in the Department of Education and Professional Studies, Faculty of Education and Health Science at the University of Limerick. He is the Course Director of the Graduate Diploma in Education (Technology) programme. Before joining the university he taught Engineering and Graphics at post-primary level.

His MA research examined post-primary teachers' use of ICT in technology rich schools. Following this research he contributed to several national studies into the use of ICT in teaching and learning including the *OECD/CERI ICT* programme 'Case Studies of ICT and School Improvement' and the national report into the feasibility of introducing a computer-based subject and Leaving Certificate level. He has also been involved in several curriculum development projects at a national level including the use of parametric CAD software in post-primary schools. His doctoral research examined teacher professional development and focused on the challenge posed by emerging technologies. He is currently engaged in a number of research projects exploring the use and management of ICT in post-primary schools as well as innovations in teaching and learning at third-level education. He is a former recipient of the University's Teaching Excellence award.

## Eddie Norman

*Professor of Design Education*

*Design Education Research Group  
Loughborough Design School  
Loughborough University*



Eddie joined the Department of Design and Technology, which has now become part of Loughborough Design School, in 1984. He has taught modules relating to design contexts, materials, mechanics, prototyping, sustainable design, design education and design practice on the Industrial and Product Design and Technology degree programmes. In 1990 he collaborated with three others to produce the first A' Level textbook for Design and Technology, *Advanced Design and Technology*, which has sold over 30,000 copies and is now in its third edition. His PhD was awarded in 2002 in recognition of published work concerning *the technological base of design and associated pedagogical issues*.

In recent years Eddie's contribution has focussed more towards research. He is leader of Loughborough's Design Education Research Group and editor of *Design and Technology Education: an international journal*. His research has explored the act of designing, and particularly the roles played by knowledge, skills and values in design decision-making. However, in this context, perhaps his most significant experience is as being Co-Editor of *IDATER* from 1998-2001 and Chief Editor of the *D&T Association's International Research Conferences* from 2002-2010. It is from these events that his interest in the potential of online

conferences stems. The IDATER paper archive can be found at <https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/954> and the D&T Association Conference archive at <https://dspace.lboro.ac.uk/dspacejspui/handle/2134/2767>, or by visiting the online DATER (Design and Technology Education Research) hub at [www.dater.org.uk](http://www.dater.org.uk).

He is also co-founder of *Cool Acoustics* with Owain Pedgley, a Loughborough University venture developing polymer acoustic guitars. He has been awarded a NESTA Invention and Innovation Fellowship, a HEROBC Innovation and Regional Fellowship, a Gatsby Innovation Fellowship and a Lachesis Fund Award to pursue their development. The first prototype all-polymer guitars were launched in Frankfurt in 2002 and recognised as one of the first significant innovations in acoustic guitars since the 1930s. More recently, this work has led to an interest in design for music therapy with his daughter Liz (a music therapist). Further information about the development of polymer acoustic guitars can be found at [www.coolacoustics.com](http://www.coolacoustics.com) and about designing for music therapy at [www.musical-research.org.uk](http://www.musical-research.org.uk).

## Dr Owain Pedgley

*Associate Professor of Industrial Design*

*Middle East Technical University  
Ankara, Turkey*



Owain has been a full-time faculty member of the Department of Industrial Design, Middle East Technical University (METU) since 2007. His specialist areas of teaching and research are final year design projects, design for interaction, and materials and manufacturing. He is also the Programme Coordinator for the METU-TU Delft Joint MSc in Design Research for Interaction, and has supervision responsibility for several PhD and MSc students. Owain has published his work in leading journals including *Design Studies*, *Design Issues* and *International Journal of Design*, as well as numerous international conferences.

Prior to his emigration to Turkey, Owain forged a strong foundation to his academic and design career in the United Kingdom. In 1995 he received his BSc in Industrial Design and Technology from Loughborough University, followed in 1999 with his PhD from the same institution for research in the area of materials and manufacturing decision-making by industrial designers. The PhD contained a longitudinal case study – the design of a polymer acoustic guitar – as a source of research data. Although now over ten years on, his doctoral work continues to be cited and highly respected worldwide as an exemplar of good practice in ‘research

through designing’ or ‘practice-based research’.

Owain gained commercial design experience for three years as a product designer in the sports equipment sector, before returning to Loughborough University to co-found *Cool Acoustics*, with Eddie Norman, as a venture to design and develop polymer acoustic guitars. Alongside Eddie, Owain has been awarded a HEROBC Innovation and Regional Fellowship, a Gatsby Innovation Fellowship and a Lachesis Fund Award to pursue instrument development. The first prototype all-polymer guitars were launched at the Frankfurt Musikmesse in 2002 and were recognised as the first significant innovation in acoustic guitars since the 1930s. Owain continues his collaborative links with the newly formed Loughborough Design School through his position as Visiting Fellow.

## Anthony Rynne

*Lecturer*

*Technology Education Research Group*

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Technology*

*University of Limerick*



Anthony has been teaching Engineering Design Graphics and CAD courses on concurrent undergraduate teacher education programmes since 1986, firstly in Thomond College of Education and since 1991 at the University of Limerick. He currently teaches a number of graphics and CAD based modules to students on both the Materials and Architectural Technology and Materials and Engineering Technology undergraduate teacher education programmes at the University. He also lectures on design and CAD modelling courses across a range of other programmes at UL including Product Design, Manufacturing Engineering, Digital Media and Construction Management. He has also taught CAD modelling on post-graduate Masters Programmes at the University for many years. Anthony is a Certified SolidWorks Professional (CSWP) and has delivered courses on parametric CAD and associated pedagogy to the State Examinations Commission (SEC) and the Department of Education and Science inspectorate and has consulted with industry on CAD modelling strategies. Anthony is the co-author of a Junior Cycle textbook on Technical Graphics and is the author of the textbook for the CAD Modelling blended learning module on the

Atlantic University Alliance (AUA) Modular Programme in Science and Technology Studies.

Anthony is currently Course Director of the Materials and Architectural Technology programme and is a member of both the Department's Technology Education programme management board and the Technology Education Research Group (TERG). He is currently undertaking research on developing CAD modelling expertise.

## Dr Niall Seery

*Lecturer*

*Technology Education Research Group  
Department of Design and Manufacturing  
Technology  
University of Limerick*



Niall began his academic career in the Department of Education and Professional Studies at the University of Limerick in 2003 teaching on the first PGCE programme in technology education. He then joined the then Manufacturing and Operations Engineering Department where he took responsibility for teaching on the Concurrent undergraduate initial teacher education programmes (Materials and Engineering Technology Education and Materials and Construction Technology Education). Niall has taught Design and Communication Graphics, Process Technology and graphical and engineering pedagogics at both postgraduate and undergraduate level. He is an active member of both undergraduate initial teacher education Course Boards and sits on the Department's Technology Education programme executive board. Over the past number of years Niall has been proactive in programme review and development.

Niall's PhD, which was awarded in 2005, explored the specific learning characteristics of engineering students and the efficacy of aligning teaching and learning strategies. The resultant questions surrounding constructive alignment led his research interests towards exploring the definition of subject content knowledge within design driven education.

From 2003 to 2005 Niall acted as co-principal investigator on the CAD in

schools research project, concluding in a national report that was jointly funded by the National Council for Technology in Education (NCTE) and the National Council for Curriculum and Assessment (NCCA) (McGarr, O. & Seery, N. 2005). The project investigated the use of feature based parametric modelling software in Irish Second Level schools, as a precursor to the introduction and implementation of Design and Communication Graphics at Senior Cycle. In 2010 Niall established and is currently the director of the *Technology Education Research Group* at the University of Limerick. This group housed in the Department of Design and Manufacturing Technology aims to advance technological education and support the continuous development of practitioners, initial teacher education, and second level pupils. Niall actively reviews for a number of international research conferences and is involved in a number of collaborative research projects. To-date, Niall has supervised three PhD students and one Masters Student to completion. He is actively engaged in postgraduate supervision and is focused on developing the strategic direction of the TERG research group.

## Dr Donna Trebell

*Director, DMT Education Consultancy Ltd*

*Design Education Research Group  
Visiting Research Fellow  
Loughborough Design School,  
Loughborough University*

Donna is an experienced educator who has spent 20 years in secondary education undertaking a range of roles including Advanced Skills Teacher on a Leadership Team; County based AST, Lead AST for the West Kent Learning Federation, Principal Education Consultant with WSP Edunova and Director at DTM Education Consultancy. Through this experience she has developed an extensive knowledge and understanding of teaching, learning, leadership and management at secondary level across a range of educational contexts.

When working for WSP Edunova, Donna focussed on projects within the Building Schools for the Future and Academies Programme and is therefore familiar with National and International best practice in learning led design. This has necessitated the need to work as a key part of a multi-disciplinary design team consisting of architects, engineers, ICT specialists and contractors in order to ensure that the design solutions met the educational brief across a wide range of projects. This work has challenged leaders of learning at all levels to reflect on practice by reviewing national trends and considering the relationship between these trends, pedagogical approaches, space requirements and the effective equipping of space.

In her role as Director at DTM Education Consultancy Ltd Donna focusses on the following key areas:



Academy Design Development  
Transforming Learning Outcomes in  
Design and Technology  
Higher Education including External  
Examining and Visiting Lectureship  
Research  
Bid writing

Donna's passion for education is enhanced by an interest in research developed through years of pursuing the synergistic relationship between research and practice through masters and then doctoral level study. Having gained her doctorate in Design Education in 2008, Donna became a Visiting Research Fellow with Loughborough University's Design School and gained a place on the Editorial Board for Design and Technology Education: an international journal. She is a member of Loughborough's Design Education Research Group and regular contributor to the Design and Technology (D&T) Association's International Research Conferences.

Donna's research initially focussed on studying authentic designerly activity in secondary design and technology. However, as her career has progressed so to have her research interests. She now focuses on multi-disciplinary interaction in learning led design and the relationships between modelling and interaction.