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Contents:

SPECIAL EDITION EDITORIAL: DRAWING IS THINKING

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This collection of papers came about as the result of on-going discussion between contributors to the Thinking through Drawing symposium series. The first symposium, in 2011, highlighted the growing ability to describe and explain the phenomena of drawing in the language of cognitive science. We learnt of established and innovative practices that use drawing to enhance and facilitate cognition across many disciplines. A renewed interest in drawing as a medium for thinking was noted, emerging from these new understandings and from interdisciplinary collaborations between artists, designers and experts in other domains, such as medicine. This led us to consider whether such developments are, or could be, successfully integrated into curricula and teaching practices.

In 2012, we invited practitioners from a broad range of disciplines to share experimental and innovative uses of drawing, and discuss the broader implications of such developments. We were particularly interested in uses of drawing outside of art and design, and the potential for creative exchange and blurring of disciplinary boundaries. We invited contributions that addressed uses of drawing in STEM disciplines (Science, Technology, Engineering and Maths). Our theme “Drawing in STEAM” was inspired by the STEM to STEAM initiative, championed by Rhode Island School of Design and U.S. educators who advocate for the infusion of Art and Design into STEM education. We received proposals from surgeons, dentists, computer programmers, and many others who put drawing to a vast range of uses. Some were experimental and innovative, others drew from long-standing traditions and conventions.

Some drawing methods have stood the test of time, while others are declining and new practices are emerging. In the meantime, drawing’s presence in our schools, colleges and universities waxes and wanes. While artists and art teachers have long defended the value of drawing practice for visual thinking, it’s only recently that the scientific community has taken an interest in drawing and cognition, and now begins to offer evidence to demonstrate and explain that value, strengthening arguments that drawing can facilitate thought. These arguments are not new, but are now able to make use of the language of empirical sciences as well as that of the arts and humanities. Even with little drawing ‘skill’ or experience, drawing can enhance performance in cognitive activities such as problem solving, ideation, invention, memorisation, way-finding, arithmetic, analysis, decision making, and skill acquisition. Pencil and paper extend the mind: externalising ideas, increasing working memory, crystalising emerging ideas, enabling discovery as drawers respond, elaborate and revise evolving marks on the drawing surface, allowing margin for invention to be born from ambiguity. Even gesturing in the air without pencil or paper has been shown to enhance cognitive functioning, but ideas and gestures spread about a page can be seen all at once, by many eyes, and across language boundaries. Situated and embodied cognitive paradigms unlock new understandings of the potential of drawing as a powerful tool for thought.

These understandings can inform current debates around the role of drawing across curricula. Are we making best use of drawing as a resource for facilitating cognitive development? Are we preparing students adequately for engaging with the world, equipping them with perceptual and visual thinking skills? Concerns about 'visual literacy' are voiced by Raquel Pelayo, who acknowledges younger generations' different relationships to visual information. Such positions invite us to re-consider traditional notions of literacy to include non-verbal modes of reasoning and communicating. Such arguments can be strengthened by evidence based studies, and it seems there is much scope for educational innovation that capitalises on visual intelligence.

Gemma Anderson's collaborative project invites us to examine drawings of ideas as well as of things, illustrating how drawing can be used both to communicate mathematical reasoning, and to demonstrate mathematical proof. While the drawings in Anderson's collaborations reflect the "different logics of the artist and the mathematician" we are also presented with their common grounding in visual/spatial reasoning. We are reminded that the formal presentation of mathematics often omits the visuo-spatial concepts underpinning mathematicians' thinking. As such, the project invites us to consider the potential for further cross-fertilisation between disciplines in both research and education. In this vein, Lynn Goldsmith et al. advocate the development of "boundary crossing minds" and challenge "contemporary education's self-imposed segregations" in their study of geometric reasoning. Their study marries empirical evaluation with propositions for educational innovation that acknowledge the contribution of drawing and visualisation in geometric reasoning. They anticipate further steps that use findings such as theirs to inform teacher education, and the rolling out of useful drawing practices across curricula. Similarly, Sheilagh Carpendale and Jagoda Walny analyse how sketching is used to aid a variety of tasks, in order to inform the development of interactive visual thinking tools.

Katherine Garner's analysis of protein interactions is a perfect example of 'drawing as learning' in biomolecular research. Her project demonstrates how drawing can play a key role in every stage of the research cycle: "from digesting the wider scientific literature and conceiving new hypotheses, planning time and experiments, to the integration of experimental results within the existing framework of understanding".

Drawing as a facilitator of reasoning is a central theme here, but traditional representational and observational practices are also of renewed interest. Lucy Lyons' work shows us how simple observational practices have potential to benefit biology students and researchers by offering a slow and direct engagement with primary subject matter. Pelayo illustrates the importance of visual attention in observational drawing ability, shedding light on the perceptual complexity the skill involves. Linda Carson and James Dankert offer an objective measure for assessing representational accuracy, a tool that can perhaps help de-mystify the assessment of observational skills in both teaching and research. Howard Riley et al. are also among those who value representational skills, recognising their continued (but perhaps changing) relevance, and art & design students' continued desire to acquire them. Riley et al.'s teaching strategies acknowledge the "growing body of psychological evidence for perceptual enhancement in drawing" (Riley et al.) and draw from a cognitive understanding of the perceptual processes they seek to enhance. However, we are also reminded that those perceptual abilities might very well remain confined to drawing activity unless their transferability is made explicit. Goldsmith et al. encourage drawing instructors to "make explicit the connections across disciplines." They suggest teachers from Arts and STEM disciplines might teach common principles together.

Cognition involves more than rational, conscious thought processes. Harriet Edwards describes 'supra-rational' modes of practice: "intuitive, tacit, material and so forth", considering their role in both drawing and writing. Edwards reminds us of the ineffable aspect of creative thought.

David Kirsh discusses the role of our moving bodies in thought and learning: they are able to make understated gestures with an implicit understanding of what is known and what still needs to be rehearsed, a pared down 'sketching' though gesture. As well as thinking with our bodies, he discusses thinking with "other things", describing a cycle of 'creating, projecting and creating structure' reminiscent of Barara Tversky's concept of 'constructive perception'. In this cycle we use the external world to anchor and support creative thinking, extending the capacity of our minds through tangible interactions.

These studies and findings are also complemented by reflective accounts of drawing process given by practitioners themselves. Eduardo Corte-Real reminds us here of people's widespread and ongoing desire for the ability to make graphic representations He argues that observation is the core of drawing practice in general as the skill involves 'knowing' how to draw on many levels: procedural, geometrical, abstracted, gestural, cultural, interpretive and reflective.

In addition, we are presented with a touching reminder that drawing can facilitate not only cognitive, but affective learning. Mario Minichiello, Liz Anelli and Diedre Kelly's collaboration for Birmingham Children's Hospital Liver Transplant Unit responds to the need for non-verbal communication in difficult and sensitive medical situations. Clearly, learning to understand and face life's challenges is as vital as any other kind of learning, even if it is hard to measure the impact of such interventions. In their project we see how even distressing experiences can be made easier by drawings. Likewise, Jill Journeaux and John Burns' work shows us how drawing can help adults come to terms with illness and suffering: by understanding, labelling and communicating it non-verbally, metaphorically and even aesthetically. Their drawings and animations offer an account of a personal journey that is both insightful and inspiring.

Together these contributions represent a broad spectrum of considerations that point to a shift in the way we consider the value of drawing and visualisation across disciplines and curricula. The contributors to this volume continue to explore this shift, and together offer a glimpse of ways in which drawing practices will continue to be relevant and useful in the future

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Special Edition:
Drawing in STEAM

DRAWING AND MATHEMATICS: GEOMETRY, REASONING, AND FORM

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In this paper we consider various ways that drawing occurs in mathematics. We describe, and give examples of, drawing-based mathematical proof: in this context drawing is a language for communicating mathematical reasoning. We then describe our artistic collaboration, where drawing functions both as a language for interdisciplinary communication, essential to the formative process, and as the artwork itself.

The literature on the connections between mathematics and the visual arts tends to emphasize the mathematics and aesthetics of proportion and form, through for example the Golden Ratio $\varphi = \frac{1}{2}(1+\sqrt{5})$ and the Fibonacci Series, or to track the influence of mathematical geometries on artists such as Dorothea Rockburne and Naum Gabo. In this paper we consider a quite different connection between mathematics and the arts, which has so far been overlooked: the role of drawing in mathematical proof. This is one of several ways in which drawing occurs in research mathematics. As we have argued elsewhere (Anderson et al 2014), mathematicians and artists both use drawing as a way of coming to know and understand the world—indeed this shared way of knowing has been crucial to our mathematical/artistic collaboration. These new and underexplored connections between mathematics and visual art merit a careful analysis.

Drawing as Mathematical Proof

A mathematical proof is a step-by-step sequence of deductions, where each step is a logical consequence of the step preceding it. This sequence starts from something that is known to be true and ends with the statement to be proved. We introduce and illustrate the notion of drawing-based mathematical proof by giving an example: a drawing-based proof of the famous Theorem of Pythagoras.

THEOREM OF PYTHAGORAS

In a right-angled triangle, the square on the hypotenuse is equal to the sum of the squares on the other two sides.

What does this mean? "The hypotenuse" is the longest side of a right-angled triangle; this is always the side opposite the right angle. So the Theorem of Pythagoras is the assertion that if the sides of a right-angled triangle are of lengths *a, b,* and *c* as shown:

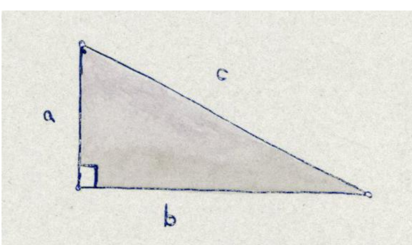

FIG. 1

then $a^2+b^2=c^2$.

Let us prove this. First, consider a square with side-length $a+b$, divided as shown in Figure 2. The left-hand shaded square in Figure 2 has side-length a, and hence area a^2. The right-hand square in Figure 2 has side-length b, and hence area b^2. Each of the four triangles in Figure 2 is a right-angled triangle with the two shorter sides having lengths *a* and *b*. Thus each of the four triangles in Figure 2 is a copy of the triangle shown in Figure 1; in particular, therefore, the hypotenuse (longest side) in each of the four triangles has length *c*.

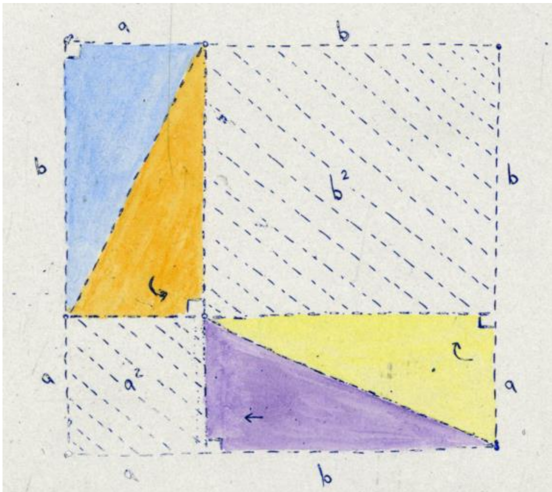

FIG. 2

Now consider a square of side-length *a+b* but divided differently, as shown in Figure 3. Each of the four triangles in Figure 3 is (once again) a right-angled triangle with the two shorter sides having lengths *a* and *b*. Thus each of the four triangles in Figure 3 is (once again) a copy of the triangle shown in Figure 1. The shaded square in Figure 3 therefore has side-length *c*, and area c^2.

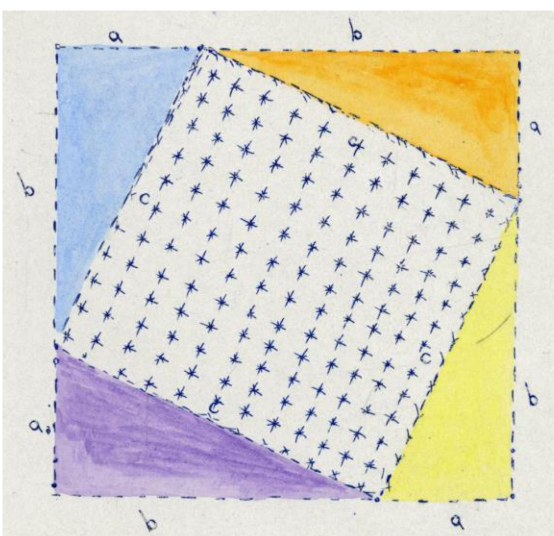

FIG. 3

Now the total shaded area in Figure 2 is equal to the total shaded area in Figure 3, as they are each equal to the area of the big square minus the area of four copies of the triangle from Figure 1. But the total shaded area in Figure 2 is a^2+b^2, and the total shaded area in Figure 3 is c^2. We conclude that $a^2+b^2=c^2$. QED

Drawings, Diagrams, and Diagrams

The drawings that formed the basis of our proof of the Theorem of Pythagoras are what might more typically be called *diagrams*. By diagram here we mean:

> *an illustrative figure which, without representing the exact appearance of an object, gives an outline or general scheme of it, so as to exhibit the shape and relations of its various parts (OED online)*

Our next example of a drawing-based proof will involve a branch of mathematics called knot theory. In knot theory, the word *diagram* has a technical meaning: it means a picture (or, more accurately, a projection) of a mathematical knot. But, as we will explain below, only the crude shape of these pictures is important. One should think of the figures in the next section as drawings of imaginary objects (as in Figure 4) or as hints as to how to manipulate these objects within your mind (as in Figure 6). We will refer to the figures as *diagrams*, following customary usage in knot theory, but the reader should be aware that the meaning of this word has changed.

UNKNOTTING NUMBER

For a mathematician, a knot is a closed curve in three-dimensional space, which can twist around in any way that you like but which never crosses itself. By "closed curve" we mean "curve with no ends". In other words, if you were to make a mathematical knot from a piece of string then you should finish by sealing the two ends of the string together. Here are two examples:

FIG. 4

The diagram on the left is a picture of the simplest possible mathematical knot, called the *unknot*. The diagram on the right is a picture of the second-simplest knot, called the *trefoil*. Notice how the crossings of the diagram show how the curve making up the knot passes over or under itself.

Mathematicians study knots for many reasons. One of us (Dr Dorothy Buck) studies how DNA molecules become knotted and linked during cellular processes such as replication and recombination, and how these changes in form affect the biology of the cell. Thus knot theory is of interest to mathematical biologists. But knot theory started as, and remains, an important part of the field of *topology*: the mathematical study of shape[1].

We regard two knots as the same if you can smoothly deform one of them into the other, without breaking the curve or pushing it through itself. For example, the knot pictured in Figure 5

FIG. 5

is actually the unknot: to see this imagine pulling the loop in the middle tight, and then untwisting it. It is much easier to draw this sequence of transformations than to describe it in words — see Figure 6.

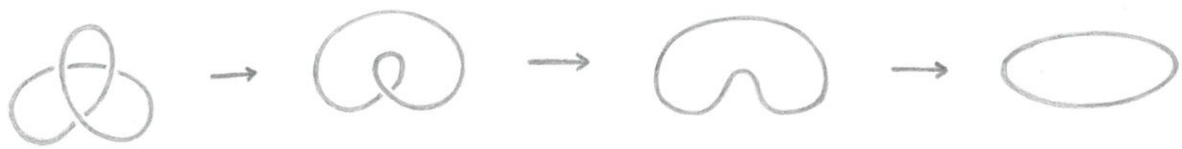

FIG. 6

Figures 4, 5 and 6 also illustrate an important point: just because two pictures of a knot are different does *not* mean that the knots themselves are different. The knot in Figure 5 and the knot pictured in the left-hand diagram in Figure 4 are the same even though the diagrams are different. The fact that these two different diagrams represent the same knot is demonstrated in Figure 6.

We now turn to our second example of a drawing-based mathematical proof. For this we need to introduce a new concept, *unknotting number*. The unknotting number of a knot is a measure of the complexity of that knot. It is the minimum number of times that you need to push the curve through itself in order to turn it into the unknot. In terms of a diagram of the knot, pushing the curve through itself corresponds to turning an undercrossing into an overcrossing, or *vice versa*:

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[1] Dr Buck is both a topologist and a mathematical biologist.

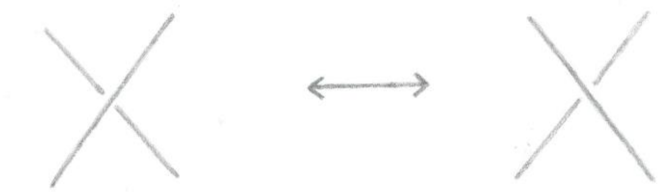

FIG. 7

The following diagram shows that the unknotting number of the trefoil is one: if we take the standard picture of the trefoil and change one of the crossings[2] from an overcrossing into an undercrossing or *vice versa* then you get the unknot.

FIG. 8

Let us finish this section with a more complicated example: we will prove that the unknotting number of the knot called 8_{10}, which is shown in Figure 9, is two.

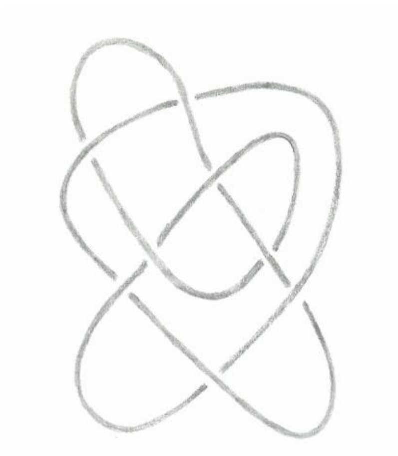

FIG. 9

First, change the crossing indicated from an undercrossing to an overcrossing (or in other words, push the curve through itself once in the place shown).

[2] It does not matter which of the three crossings you change. In each case, you get the unknot.

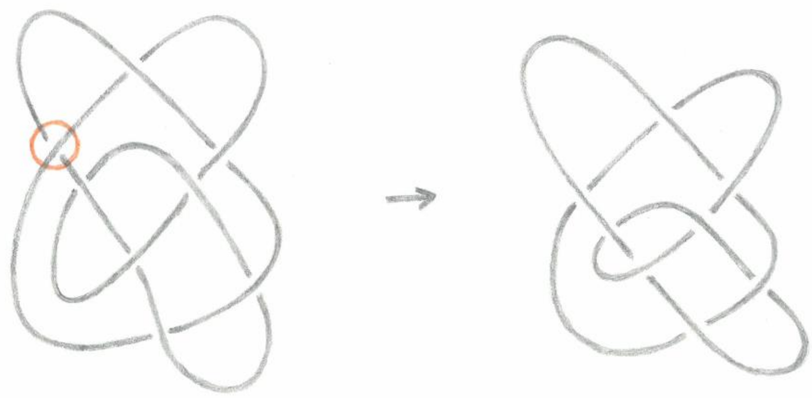

FIG. 10

Next deform the knot as shown in Figure 11.

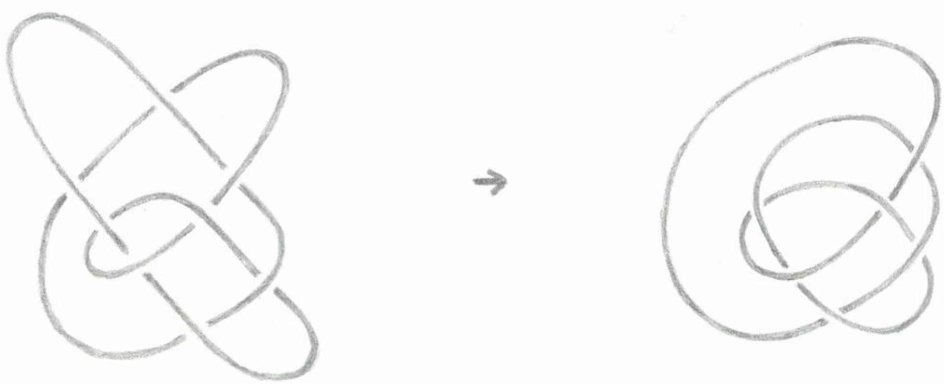

FIG. 11

Now change the crossing indicated from an undercrossing to an overcrossing (or in other words, push the curve through itself in the place indicated; this is the second time we have pushed the curve through itself).

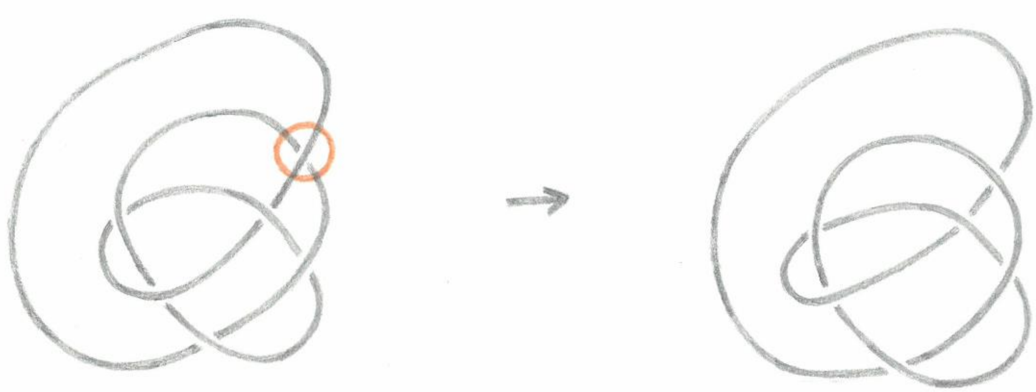

FIG. 12

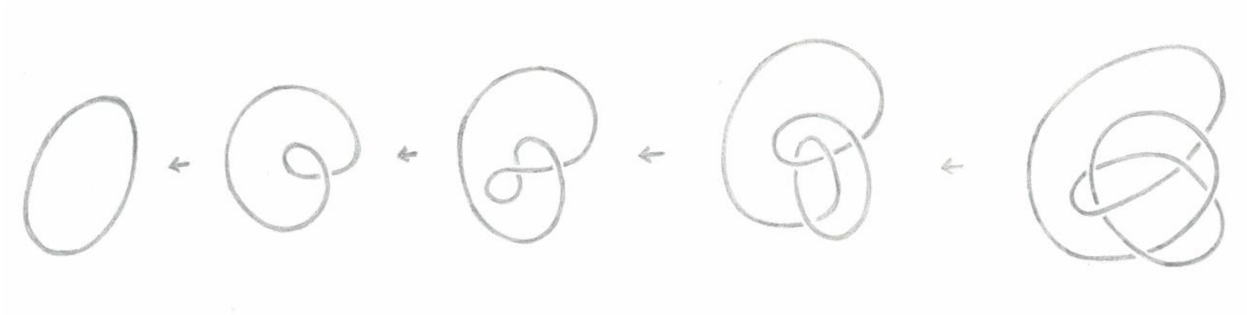

FIG. 13

Finally, deform the knot as shown in Figure 13. The end result is the unknot. Thus we have given a drawing-based proof that we can unknot 8_{10} by making two crossing changes.

Let us close this section by pointing out a subtlety. We have shown that we can unknot 8_{10} by making two crossing changes. This shows that the unknotting number of 8_{10} is at most two. But to show that the unknotting number of 8_{10} is exactly two we need to show that two is the *minimum* number of crossing changes required: in other words, we need to show that there is *no* diagram of a knot such that making a single crossing change will turn 8_{10} into the unknot[3]. This is substantially harder: it requires the full power of the Osváth–Szabó theory of Heegaard Floer knot homology (Osváth and Szabó 2005).

Our Collaboration

We now turn to our artistic collaboration. This began in 2011, when Anderson found herself reading the article ‘A Periodic Table of Shapes’ in the Imperial College Newsletter. The article described the research of Tom Coates and Alessio Corti, who study geometric forms called Fano Varieties that are “atomic pieces” of mathematical shapes.

Anderson immediately took the article back to her studio and began making drawings, exploring the Fano forms. This subsequently developed into a full collaboration, first with Coates and Corti and then later also with Dorothy Buck.

Drawing has played an essential role in our project. During hundreds of conversations about scientific ideas — about string theory, hyperbolic geometries, polyhedra, topology,

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[3] This issue did not arise when we showed that the unknotting number of the trefoil knot is one. The trefoil and the unknot are different, so the unknotting number of the trefoil is at least one. And we showed that there is a diagram where making one crossing change turns the trefoil into the unknot. So the unknotting number of the trefoil is exactly one.

knot theory, DNA, and many other topics --- drawings have formed the bridge that allows interdisciplinary communication.

These drawings are largely informal, notational, and schematic (see Figures 14 and 15). They accompany and form an integral part of conversations, with drawing functioning as a non-verbal, intuitive language for scientific concepts. The precise role of drawing differs from place to place in the conversation: communicating the visualization needed for understanding; sharpening these visualizations; or creating understanding (for the drawer) through the physical act of drawing.

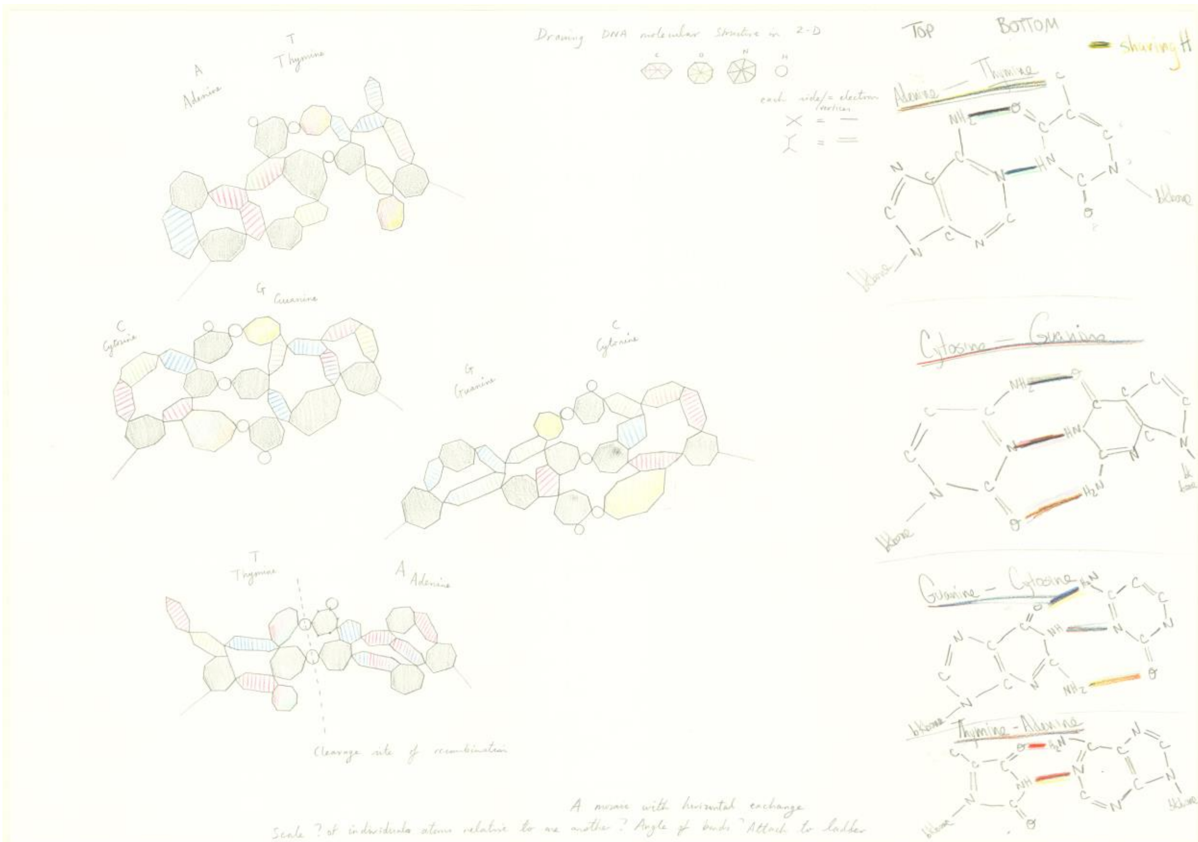

FIG. 14

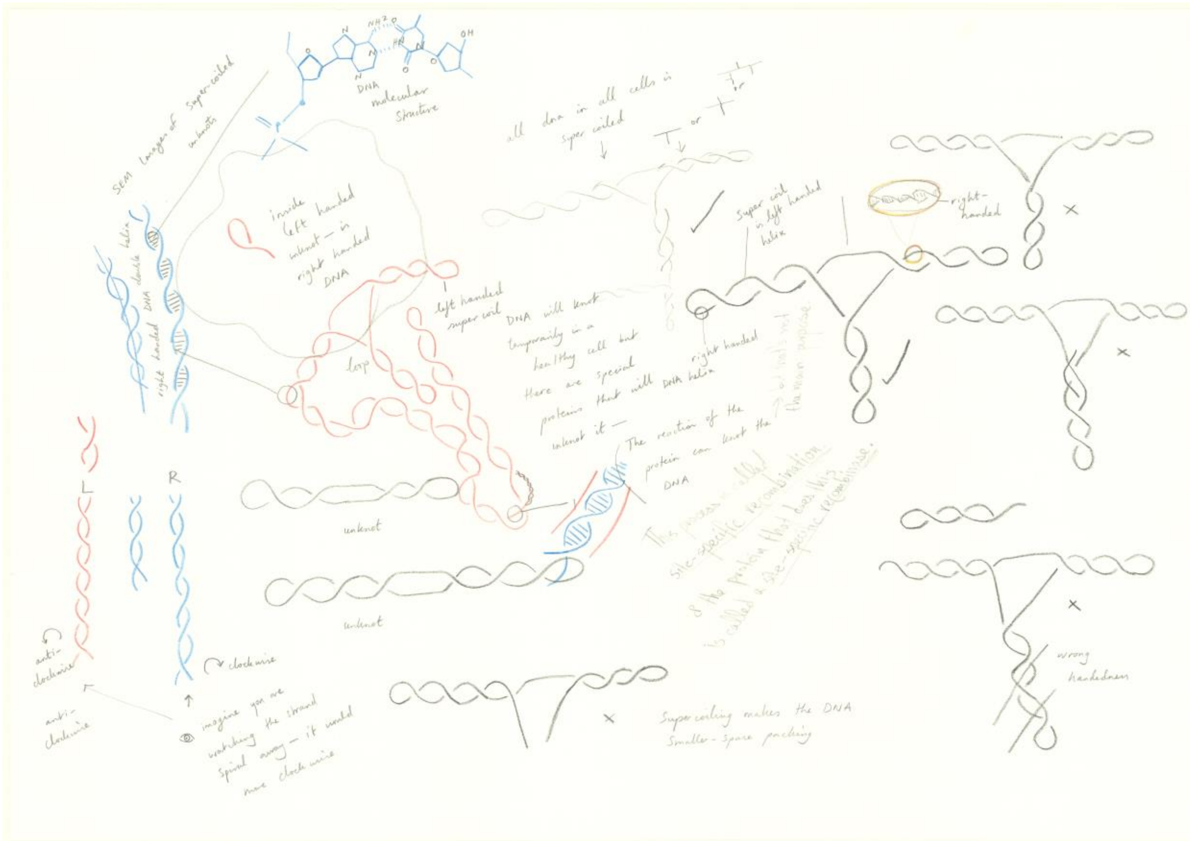

FIG. 15

Drawing also plays a different, and deeper, role in our collaboration. Because the creative processes of the mathematicians involved are heavily visual and drawing-based, Anderson can witness and connect to the process of doing mathematical research; this directly inspires artworks based on the geometries and forms involved (Figure 16). Anderson in turn responds with unique insights and resonances, the result of her practiced observational drawing across the natural world. The works that we create thus admit multiple overlapping perspectives, holding within them as they do the different logics of the artist and the mathematician.

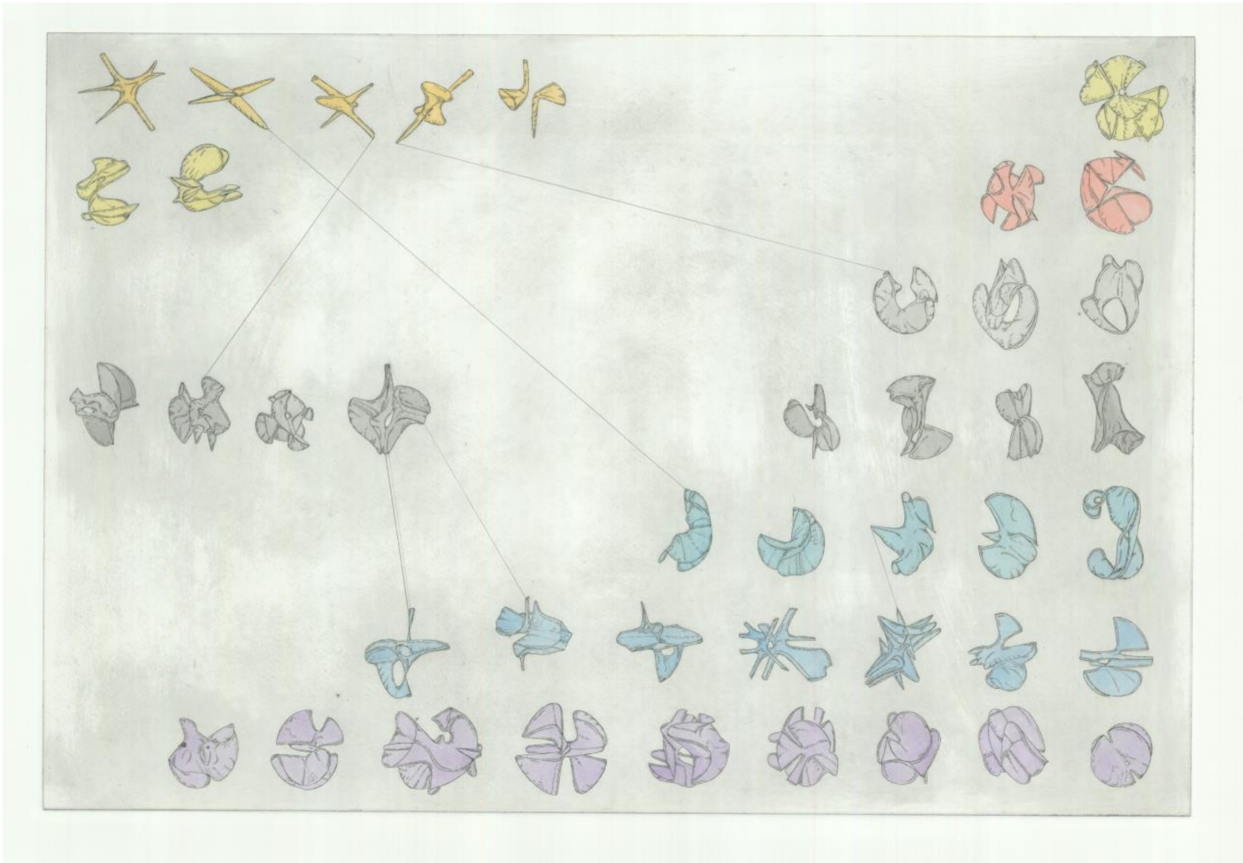

FIG. 16

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Special Edition:
Drawing in STEAM

LIKENESS, ABSTRACTION AND KNOWLEDGE: WHAT DO WE KNOW IN OBSERVATIONAL DRAWING?

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"The astonishing reality of things
Is my discovery every day.
Each thing is what it is,
And it's hard to explain to someone how much this makes me happy,
How much it's enough for me."
Alberto Caeiro (Fernando Pessoa's heteronym) 2007

LIKENESS

FIG.1. RUSSELL SQUARE, LONDON. AUTHOR'S DRAWING IN SITU, LONDON, MAY 2012

This paper is about observational drawing.

In the matter of knowledge and drawing there is a tendency to investigate the power of drawing within the process of acquiring knowledge. For this we usually isolate disciplines that use drawing both as a cognitive skill and as a procedural skill. In this case we are referring to observation as part of scientific methods, thus underlining the importance of observing through drawing, different from observing and writing, observing and photographing, observing and filming or simply observing. In this paper, however, we would like to inquire about the pure act of knowledge that observing by drawing or drawing as if observing contemplates.

One matter that interests us most is the fact that the expertise of drawing by observing is difficult to accomplish. On the other hand it is also interesting that apparently it is very easy to add meanings to very simple drawings, as we well know from Miffy, Hello Kitty and Smile. In any case, we rarely look at drawings as systems of signs of strict graphic meaning. Only a highly educated mind or, strangely, a victim of visual agnosia, (like the man that mistook his wife for a hat described by Oliver Sacks in 1998), will look at a drawing in a purely syntactical way. Looking at Fig. 1. we rapidly "respond" to the drawing by identifying "Trees", "Benches", "Lamps", "Buildings" arranged in such manner that the meaning "Park" will arise. For Londoners it may even look as a familiar place. This is crucial.

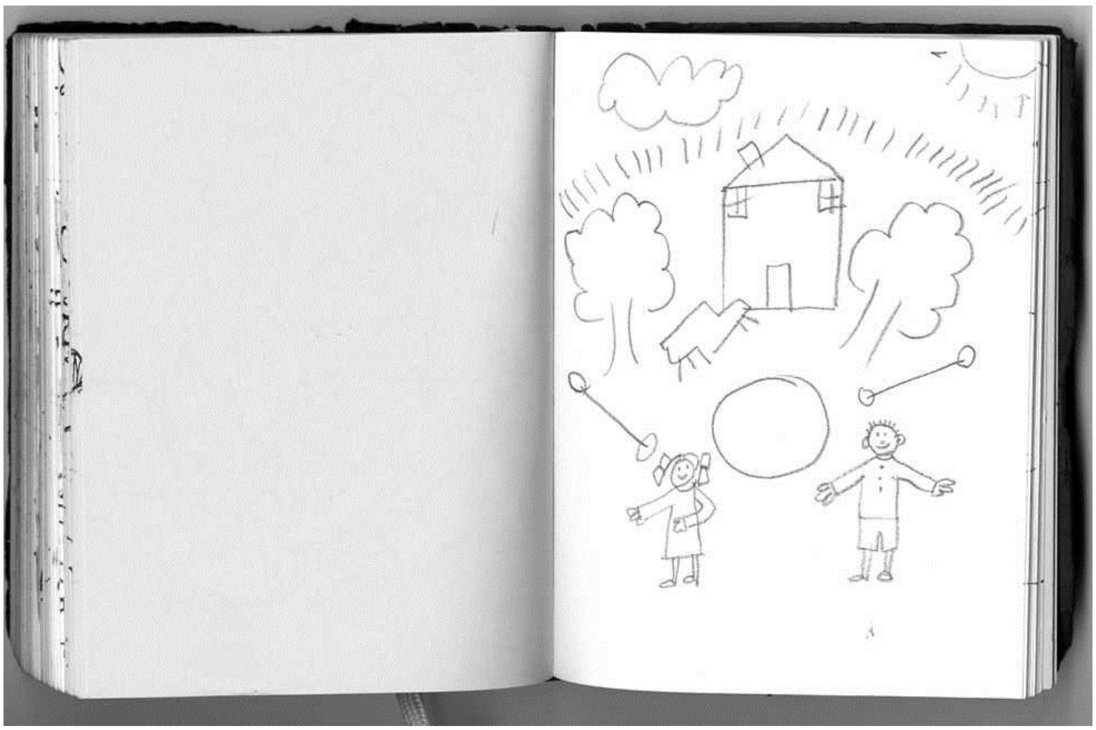

FIG. 2. RUSSEL SQUARE PARK AS IF DRAWN BY A CHILD, AUTHORS DRAWING, MARCH 2013

Whereas the same sequence of meanings could arise from Fig. 2, it would be almost impossible to recognize Russel Square's Park as seen from a determined point of view. We may admit that in both drawings, meaning is deployed by graphic conventions but only the first truly evokes the experience of observing, connecting the action of drawing with the human perceptual visual experience.

In modern times, in the so called Western Culture, is often highlighted Brunelleschi's device as the inaugural moment for drawings that look alike our perceptual visual experience. This device consisted, according to the legend narrated by the painter Mannini and studied amongst others by Martin Kemp (1990: 12,13), of a mirror, a painted tavola depicting a view of the octagonal baptistery of S. Giovanni in front of Santa Maria dei Fiori, in the city of Florence, and not less important, the represented authentic building[1]. The user, placed on a precise point, outside the doors of the cathedral peeped through a hole in the back of the tavola and rotated a mirror in front of the painting that either reflected it or, by sliding down, let the real building be seen.

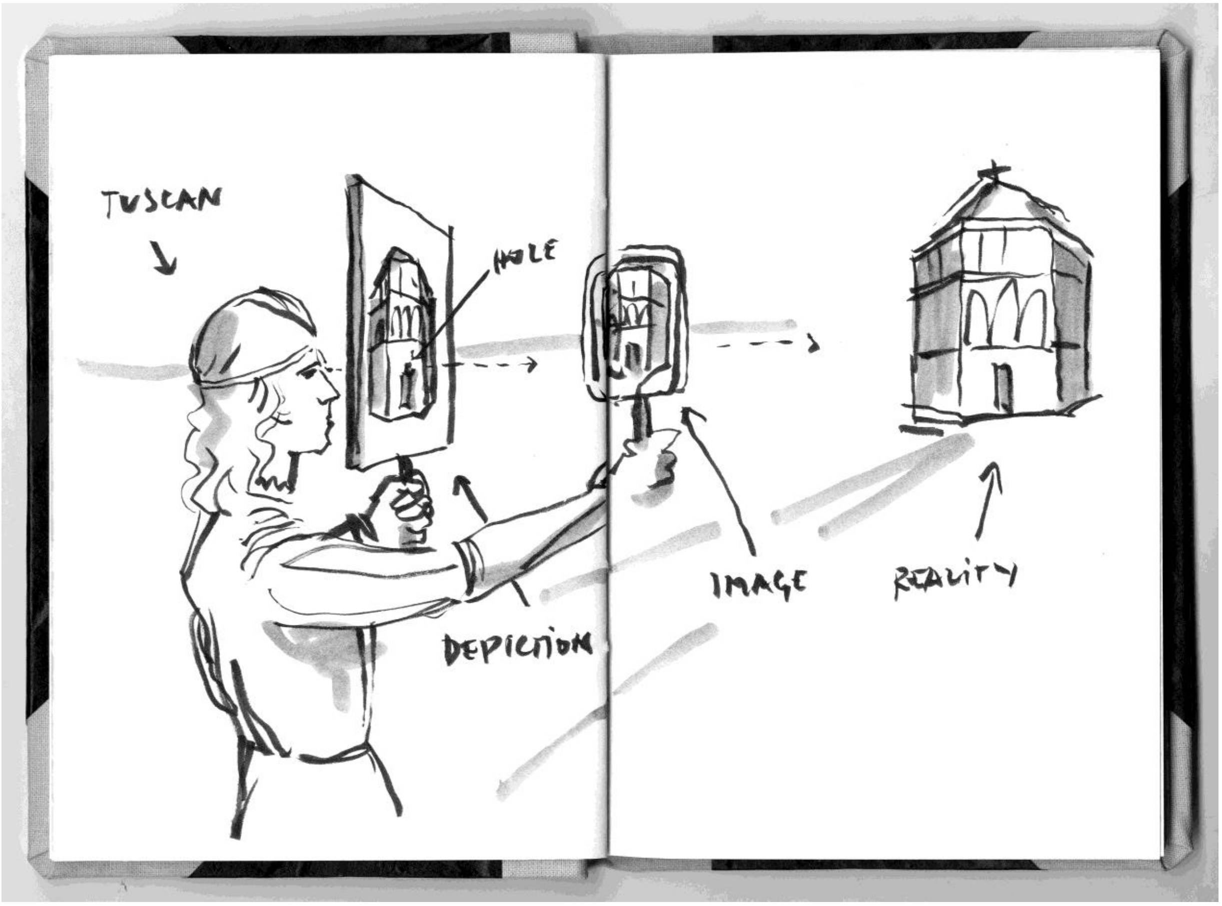

FIG.3. BRUNELLESCHI'S DEVICE. AUTHOR'S SKETCH, AUGUST 2012

This device allows us to define different concepts related to observational drawing. First: Reality. The Baptistery is something real. It has all the attributes of reality. We cannot go through its walls, we are protected from rain inside, and we see it from a certain distance as well as closer. If we care to test it, it even has smell and taste. Second: Image: The entity that is formed in the mirror. It might sometimes fool us, and be mistaken for reality, but the baptistery in the mirror is clearly an image of the baptistery's depiction existing only because the real painting exists. This is not reversible; there is a hierarchy between them. Third: Depiction. Although also an image, a depiction has a technical demand that is not

[1] Kemp describes also a similar device with the Palazzo della Signoria. The perspective on this case would demand two vanishing points. In the early Renaissance this method was not yet controlled so it is even more legendary.

automatic. Also, the difference between the image in the mirror and the one in the tavola is that we can't stop the mirror from producing countless images when moving. However, the depiction is fixed on that view of the baptistery, even if you carry it all the way through the bridge over the Arno River and put it in front of S. Lorenzo church.

Because we see things and understand that we are seeing, we can also say that we form images that we call mental images. We think with our brains and we only see because, not only we have eyes, but also because we have brains to process the photons transformed in nervous signals in our retina. Since we admit that the brain processes visual experiences into images we started to think that we are able also to imagine, i.e. to mentally produce images. Dreams and REM, rapid eye movements, testify this internal imagery and also its connection to the external visual apparatus.

Visual experience may be, therefore, of the purely intellectual sort, like a square (and we must admit that the experience of square, once defined, may be imagined and thus gain a visual kind even if the individual has never seen a square), or of the intellectualized sort since it restores the experience of having observed/seen something and understanding what it was. Drawing is a way of externalizing mental images by creating a new image that, if related with something real, may depict it, if it looks like the real thing. Brunelleschi's experiment was designed to show, prove and demonstrate that he had achieved a process of rightful depiction, in that sense, superior to the previous ones. The image in the mirror once reflecting the painting was exactly the same as when the mirror was not visible and thus everyone could see the real baptistery and its depiction, for what is expected in a depiction, as rightful.

Although not constructed only by observation, the painting in the tavola, as we have seen, allows us to clarify what reality may be related to an image of it and, from the countless images of it, underline depictions of it. We should clarify also that observational drawings include those done by observing things and those done as if done observing things. We shall call observation drawing to the ones done in the presence of the thing depicted and observational to both.

Dürer's devices, almost a century after Brunelleschi's, were based on the coincidence of geometry and optics. In these settings is even more clear the separation and relations between reality, image and depiction. Also we can speak here strictly of observation drawings. In Figure 4, a reclined woman is real, in the framed grid the author sees an image that is depicted in the paper.

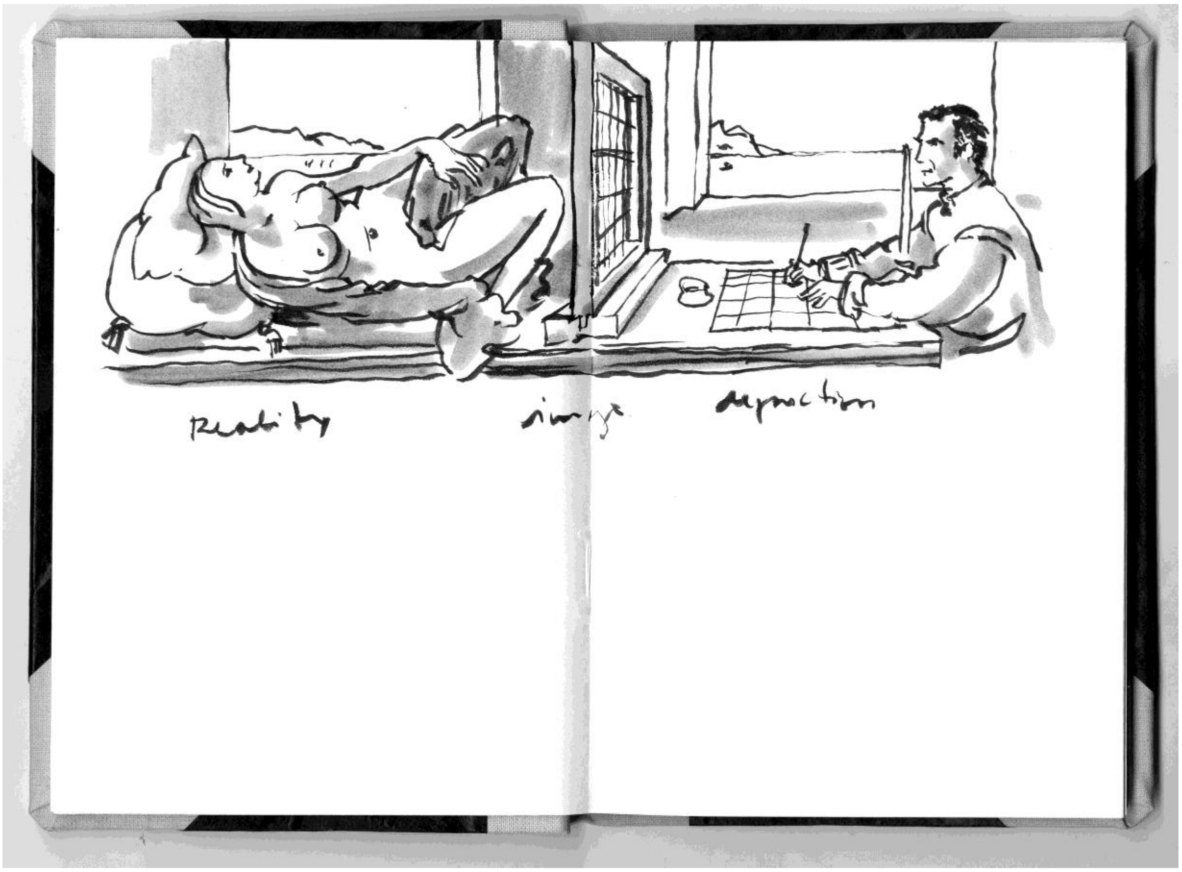

FIG. 4. ONE OF DÜRER'S DEVICES FOR APPLIED PERSPECTIVE. AUTHOR'S DRAWING FROM DURER'S ENGRAVING.

So we might say that the first knowledge an observation drawing shows is the knowledge of perspective. Not of Perspective, as a set of geometric rules, but fundamentally of perspective as a determined position relative to what is observed that creates "The Image" to be copied.

Ideally the observer should not move and the observed should be immobile also. This stillness implies that we create an observation apparatus. So, the second thing we know in observation drawing is that the device eye-brain-hand is not a simple seeing apparatus but an observation device. And a special one: a device to depict. This process of observing for depicting and depicting requires time, time made of attention, concentration, and precision. This is a conscious interruption of the normal flux of existential time. When doing observation drawing we know how to control time. This goes from micro time implied in copying a small section of reality to a bigger time, the time the author decides to give to the whole depiction. In the proceedings of the symposium on drawing, cognition and education a few authors focused on the study of time, namely Angela Brew (2011: 67-72), Ruben Cohen-Cagli (2011: 73-78) in the micro time and especially Michelle Fava (2011, pp.79-85) in the macro time. These studies emphasise that, if we really try to obtain likeness, we should concentrate on seeing entities in reality that may economically represent it, thus depicting it through its image. I say economically because it is impossible to import the whole section of reality we are observing. So we have to select forms able to be translated in lines, as we notice in most drawings. As we will see next, this is a cultural translation. So also by drawing observing we learn to translate visual information that is overwhelming in "stenography" that may be understandable in a culture.

Likeness Revealed

FIG.5. CONFERENCE LUNCH AT CHELSEA COLLEGE OF ART AND DESIGN, LONDON. AUTHOR'S SKETCH, MAY 2012

Leon Battista Alberti explained, a few years later Brunelleschi's Show in his treatise De Pictura (1435) through geometric constructions. This was consistently demonstrated by Masaccio's Holy Trinity and so many Piero della Francesca's or Vittorio Carpaccio's paintings among so many others. The geometry, explained by Alberti uncovers a process that he calls in Latin some times circonscrizone (contour) and in others lineamentis (design) which himself later translates to Tuscan Language as "disegno", as we (Eduardo Corte-Real & Susana Oliveira, 2011: 85-87) already stressed. The separation of disegno as preparation for a painting was already noted in Cennino Cennini's "Libro del Arte" written in the late thirteen or early fourteen hundreds. He describes drawing (disegno) very much as we still do it today. At a certain point, he declares: 'Sai che te avverrà praticando il disegno di penna? Che ti farà sperto, pratico e capace di molto disegno entro la testa tua. (Cennini, circa 1400-1982: XIII, 10).

[Do you know what you will gain by practicing drawing with a pen? It will make you an expert, competent in practice and able of having lots of designs in your head.]

Cennino pointed out that disegno was both external and mental. A geometric device such as prospectiva pingendi [perspective for painting], as Della Francesca later termed it in his treatise, is clearly a mental construction that, when externalized by drawing fits in visual experience. Although observational, Piero's paintings, for instance, do not depict a reality but they depict something as-reality. The Ideal Cities attributed to his circle propose a new reality presented as if it has been depicted. Although not representing any existing city in Italy or elsewhere they depict possible cities with vivid likeness.

FIG. 6. LUNCH AT PIERO'S. AUTHOR'S DRAWING IN SITU, IDEAL CITY #1, AUGUST 2012. THERE IS NO RESTAURANT IN FRONT OF THIS IDEAL CITY'S TEMPLE BECAUSE THE CITY DOES NOT EXIST, BUT IF IT WOULD EXIST IT WOULD MOST LIKELY HAVE ONE.

So, observational drawing, as we suggested before, includes observation drawing and other drawings made as if something was observed. For these drawings the problem of likeness is critical. Almost paradoxically, being alike something that does not yet exist, or may even never exist is vital for depiction's success. On this matter, knowing perspective allows us to create less ambiguity. The resemblance between perspective as geometry and optics helps greatly to achieve acceptable likeness. To make observational drawings of things that do not exist demands not only knowledge of perspective as we define it previously but requires also knowledge on how perspective works. Knowing the geometry of vision is not mandatory in drawing by observing but is easily interiorized if likeness is achieved. The same happens with conic perspective geometry. The path initiated by Brunelleschi allowed that some activities like Design or Architecture could rely on drawings of absolute likeness with things that are not yet produced or built both by conventional notation as for visual similitude. For centuries drawing as art, relied also in likeness.

Likeness that we like

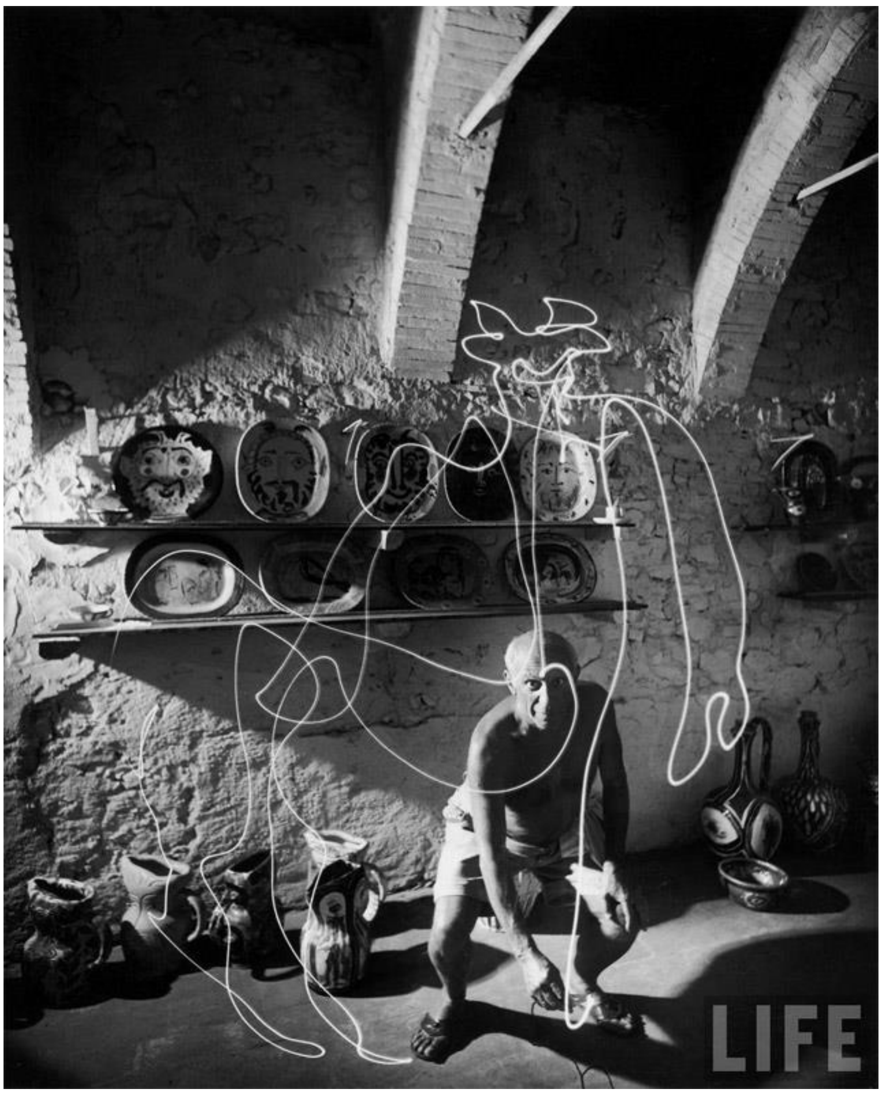

FIG. 7. PABLO PICASSO DRAWING WITH A FLASHLIGHT. GJON MILI, 1949

Some of the most famous images related to Drawing as art are Picasso's light drawings. The story of these images is briefly described in LIFE magazine's website:

> *"LIFE photographer Gjon Mili visited Picasso in 1949. Mili showed the artist some of his photographs of ice skaters with tiny lights affixed to their skates jumping in the dark—and Picasso's mind began to race. The series of photographs that follows—Picasso's light drawings—were made with a small flashlight in a dark room; the images vanished almost as soon as they were created."(LIFE website 2012)*

These images are normally shown to express immateriality in drawing and authorship in any medium. Fixed by a few seconds of exposure, the image strikes us because of its instantaneous temporality and graphic frailty. Yet the consistency of Picasso's style also strikes us (knowing that the camera had managed to see the whole picture only after the film being developed) not only because of the expressive quality of the line, but also because of the particular thematic chosen by the artist. One of the immediate exercises of the viewers is to attribute a name to what is drawn. Some drawings are more clearly about what we can call them (in fact the LIFE website call them several names such as "centaur", "elephant", "vase of flowers") and some more ambiguous. We must note that there is also an exploit character in these images in order to prove Picasso's genius. Circling around, like anyone does with a cigarette in a summer moonless night, wouldn't do the trick. Picasso uses his icons. Consequently, the drawings look like something, even the ones not particularly clear, look like something. We may discuss if the elephant is not, after all, half a bull, or if a vase of flowers isn't an explosion of a volcano. Although the images are the testimony of a gesture, they are also meaning bearers (multiple meaning bearers if ambiguous). In a sense, they correspond to the etymology of drawing and the etymology of disegno. Gesture and meaning: To draw, and to sign (di-segno).

The first lesson we may take from these drawings on the limit of Drawing (because of its instantaneous sort only revealed by photography), is that, if something is a drawing, it looks like something. In consequence, the problem of likeness in Drawing is not how to get drawings to look like something but quite the opposite: Drawings always look like something. It is almost impossible to make drawings that don't look like something. This is another standpoint of knowing through drawing: we know that drawing looks like something.

Another circumstance is that these drawings look like Picasso drawings. Of course, they were made by Pablo himself, one might say. Picasso draws them to look like his drawings. Firstly, because of the theme he chooses and secondly, because he mimed his own gestures as if he was drawing on paper or canvas. Anyone that has experienced making drawings with very small lights in the night knows that we can only see the trace of the past fraction of a second. So Picasso had only a physical memory and a mental image to rely on. This brings me to one more thing we know by knowing how to draw: drawing is a showing device. A device made not for only showing what we depict, but also for showing what our gestures look like. We know that gesture is of consequence. We know how to move our hands according to our will to the limit of artistic expression.

In that sense we like the ambiguous likeness of Picasso's drawings. But this ambiguity does not mean that they aren't alike something, it means that they are alike many things. Also to the limit of been alike other drawings, and this also deals with the cultural translation that we spoke before.

This is the one of the main notions that we have been dealing with in this paper: It is hard to find a drawing that doesn't look like something (obviously it is not the drawing that looks like something but our "incontrollable" capacity of seeing likeness that makes it look like something).

As Donald, D. Hoffman (2000: 23) placed it "The image at the eye has two dimensions; therefore it has countless interpretations". This physiological oddity doesn't trigger immediately incommensurable meanings on every sight. It points out the fact that drawings share with the image at the eye a two-dimensional nature. This means that our way of seeing drives us towards the interpretation of two dimensional images. This is equivalent to say that we are driven to interpret drawings. Drawings are petrified gestures but they are also and mostly generators of signification. The particular shape of visual entities that look like lines in the things that we observe (or create as if we were observing) is the first think that we need to know in order to draw something with lesser ambiguity. Also, by knowing this so well we might have to disregard it, if clarity is an obstacle in an artistic proposal.

So, in conjunction with the previous knowledge we have discussed (knowledge of perspective, knowledge on controlling time and knowledge of a cultural stenography), knowledge that drawings always look like something drives us further deep in understanding the nature of observational drawing. If drawings always look like something, the challenge lies in making them look like a precise thing and not alike anything.

ABSTRACTION

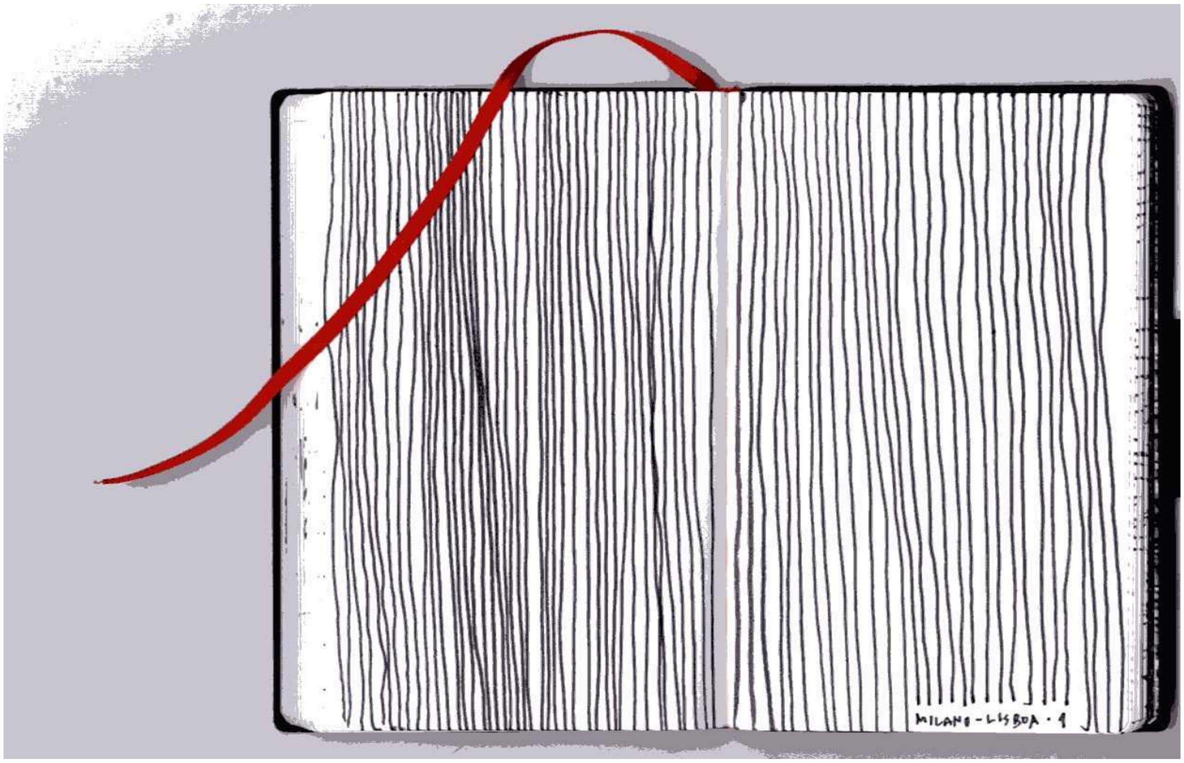

FIG.8. MILANOLISBOA, AUTHOR'S DRAWING IN FROST ART MUSEUM DRAWING PROJECT, AIRPLANE BETWEEN MILAN AND LISBON, OCTOBER 2009

> *"The words or the language, as they are written or are pronounced, don't seem to perform any role in the machine of my thoughts. The physical entities that look like elements in thought are certain signs and images more or less clear that can be «voluntarily» combined or reproduced [...t] hese elements are in my case of the visual type". (Einstein 2005 [1954]: 170)*

These were Einstein's words, in 1945, responding to Jacques Hadamard's survey about mathematical thought[2].

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[2] The quotations from Einstein are from the book edited in Portuguese as "Como Vejo A Ciência a Religião e o Mundo" [How do I see Science, Religion and the World] Trans. José Miguel Silva & Ruth San Payo Araújo, Lisboa: Relógio d'Água Editores, 2005 out of extracts from three books: The world as I see it (1954), Ideas and opinions (1954) and Out of My Later Years (1956). According to the publisher, the complete writings are still being collected and printed by the Princeton University Press…

In a conference, in 2009 held in Lisbon, Martin Kemp captured the audience attention with these words. Although discussing the intuition of artists relatively to some structures common to science, namely the platonic solids, the folding and the explosion, Kemp's quotation of Einstein introduced a question of similarity in visualizing for mathematics and visualizing for art. Although we tend to restrict mathematical thought to algebraic exercises, the matter of visualization is present in many areas of mathematics, being geometry the more evident. A cube or a sphere, or a line can be "seen" or visualized in the mind, and its nature is particularly of that kind. Yet they are considered abstract entities. Whereas likeness is commonly connected with our perceptive experience, abstraction is connected with intellectualization, although we may say that an orange looks like a sphere and, by all means, a drawing of an orange looks like a circle, looking both like an orange and a sphere.

Kemp's expertise in Leonardo Da Vinci and Science related with art conjures our interest in Einstein's statement. He speaks about entities that "look like elements" as "signs and images". Since Einstein's thoughts mentioned in Hadamard's survey deal with theoretical Physics, we may infer that the elements (signs and images) are of an abstract character.

Einstein described the relation between the sensible world and abstraction "not as the one soup has to beef but as the one a jacket has with a number in a cloak room" (Einstein 2005: 113). This means that the sensible world is not in sequence, is not of the same character, with the abstract world but there must be a law connecting both worlds. This connection allows highly complex facts in the sensible world to be processed in the abstract world. In fact, the existence of an abstract world allows the development of independent thought of the visual type, "combined or reproduced" that, due to its internal logic, may be confronted with the sensible world and more accurately describe its phenomena. The counterpart of this process neglects the complexity of individual elements and focus on relevant arrangements for their relations.

The miracle of knowledge is the miracle of a connection between the abstract world and the world itself (closer to the sensible world) by always putting on hold some of the intrinsic qualities of elements found in reality.

Apparently observational drawing has nothing to do with this. In fact it seems the opposite of this. However there is something that is worth consideration: Like in Physics, in Drawing there are very few people that are able to master the technique of producing images of satisfactory likeness with the "sensible world". And, by the way, it is even more difficult to master a technique of producing images that are not so alike reality, yet please us, as we have seen with Picasso. Also, it appears that there is an unwritten law connecting reality with depictions.

FIG. 9. PICASSO DRESSED AS STRAVINSKY IN THE EARLY 1920'S. AUTHOR'S DRAWING, AUGUST 2012

Getting back to Einstein's example of abstraction, if we deliver to a cloak room clerk a rightful depiction of our coat he will also find it. The laws of rightful depiction are more complicated than the laws of symbolization through numbers but it doesn't mean that they do not exist. If we deliver to the clerk a handkerchief to find the correspondent coat we would establish a relationship between reality and reality (soup and main course) with no abstraction in the process (besides the fact that the clerk will never find the coat). So a depiction of something is of the same order of a number standing for something. So regardless of secession of "figurative" and "abstract" made in the history of Art, figuration is also a form of abstraction.

Like in Physics, it looks like, that, in Drawing, a lot of hours of work is required, to devise an individual, system of "calculation" able to translate the normal visual experience into two dimensional notations, acceptable as look-alike representations of the sensible world.

In order to explain this fact, let's go back to Einstein. In 1933 he wrote:

> *"We revere Ancient Greece as the cradle of western science. There, for the first time, the world witnessed the miracle of a logical system that moves forward step by step with such precision that each one of its prepositions is totally certain. I'm referring to the Euclidean Geometry. This admirable triumph of reason gave to the human intellect the necessary self-confidence for its forthcoming achievements. If*

you weren't thrilled by Euclid in your teens, then you were not born to be a scientist". (Einstein 2005 [1933]: 94)

For Einstein, in this speech at the University of Oxford, Euclidean Geometry was the first step to explain that theoretical physics is axiomatic and consequently mostly mentally constructed rather than based in empirical observations. For him, Theoretical Physics belonged to the realm of imagination, where scientists strived for more elegant mathematical constructions finding new entities and new physical relations.

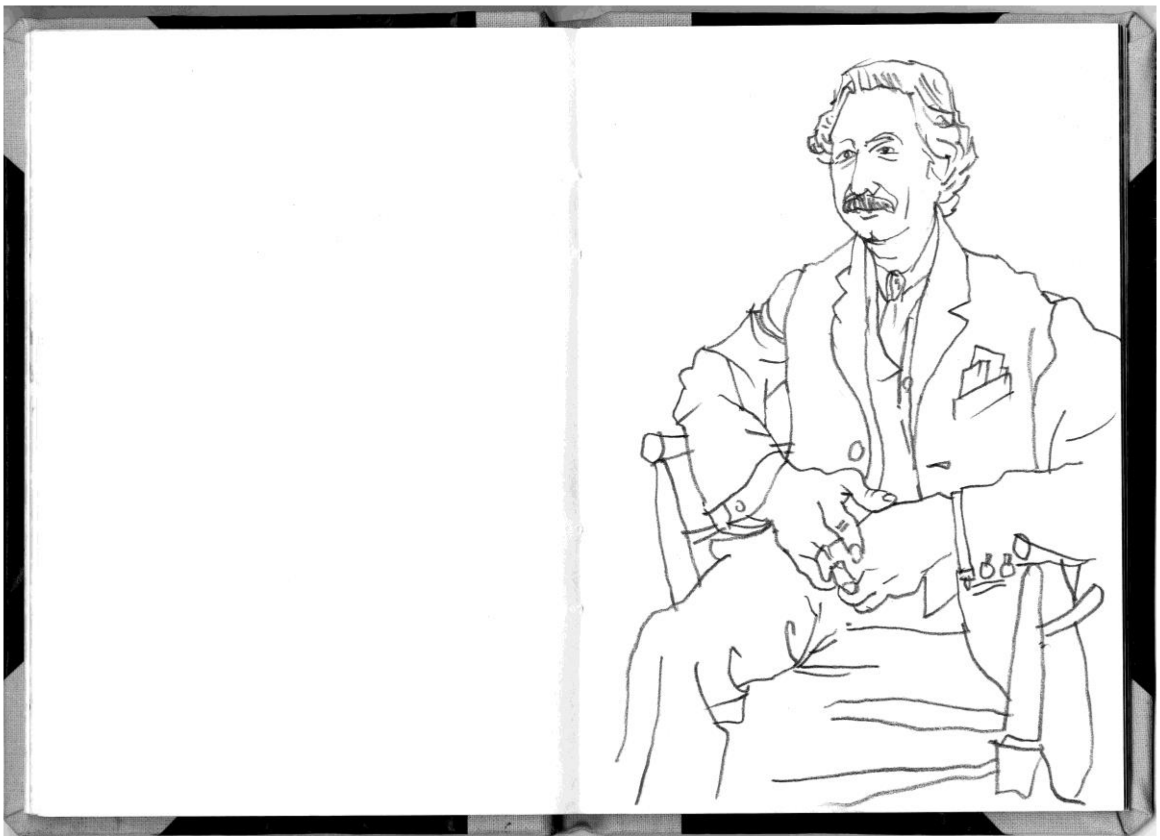


FIG. 10. EINSTEIN ALSO DRESSED AS STRAVINSKY IN THE EARLY 1920'S. AUTHOR'S DRAWING, AUGUST 2012

Euclidean Geometry was the abstraction both able to describe human constructions as well as anticipate them in a controlled manner. We navigate, see and observe in a world drawn by Euclideanism.

Whereas Euclidean Geometry, in its logical structure, anticipated modern theoretical Physics, in its application, constructed our sensible constructed world.

Furthermore we can sense the same kind of logic linking Chinese Landscape drawings and the philosophical processes of knowing related with introspection and meditation. In the same way as in Piero della Francesca's paintings, we sense "a logical system that moves forward step by step with such precision that each one of its prepositions is totally certain" in oriental observational drawing. But these are speculations. For those that learned perspective through Alberti's apparatus based on Euclidean principles we must resume to what is inherent to our culture.

Lines between Experience and Abstraction

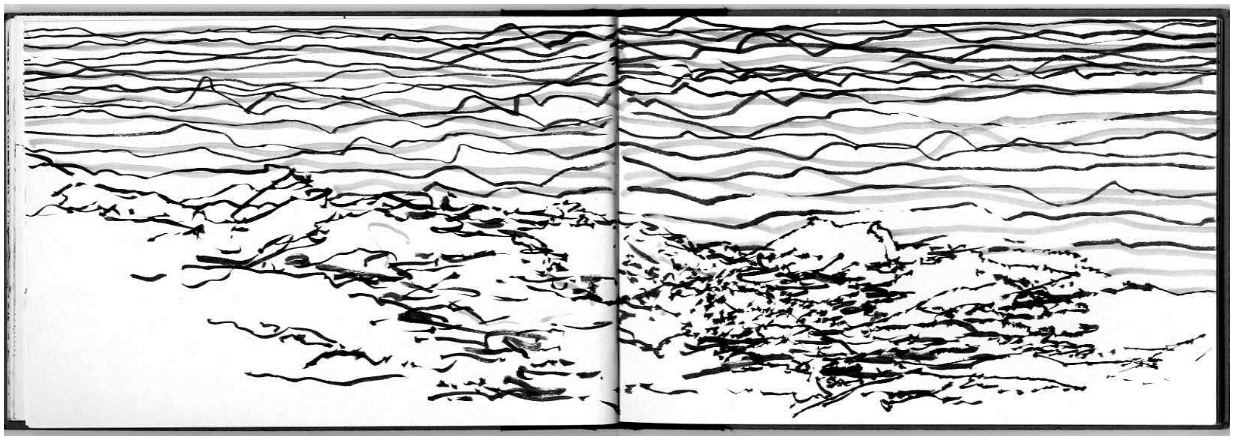


FIG.11. TRAIN DRAWING. AUTHOR'S DRAWING USING TRAIN MOVEMENTS. OPORTO – LISBON TRAIN, JULY 2012

Recently, Tim Ingold (2007) placed drawing inside the vaster realm of Linearity. On the chapter "How did the Line Become Straight" (Ingold 2007: 152-170) he gives us an account of such Euclidean endeavour put to action. Before, in the book, regarding the relation of drawing with writing the author explores the atavist notion that Drawing is "natural" and writing is "artificial" as the result of an abyss in time of thousands of years that separates the first drawings from the first writing. Then he notes:

> *"But drawing is not natural. It is not a trait or capacity that is somehow installed in all human individuals in advance of their entry into the world. Nor is writing a capacity subsequently 'added on' to a body pre-programmed to draw. Learning to write is a matter not of interiorizing a technology but of acquiring a skill. Precisely the same is true of learning to draw. Indeed writing is itself a modality of drawing; the two processes of enskilment are strictly inseparable." (Ingold 2007: 147)*

These enskilments are inseparable as forms of linearity but also as forms of abstraction that exist in its own set of rules conducting to and ideal complete transference of meaning. However, the process of 'artificial' abstraction seems to be even deeper. Verticality and Horizontality as well as parallelism are subdued but present in learning how to write and draw. The horizontal alignment of words and the parallelism of horizontal lines in a vertical development rule the world of writing as horizontal and vertical limits rule the world of drawing in a similar way. These invisible grids, although similar are used in different ways in drawing and writing.

An exercise that I always propose to the students in the first day of observation drawing course is represented in fig. 12.

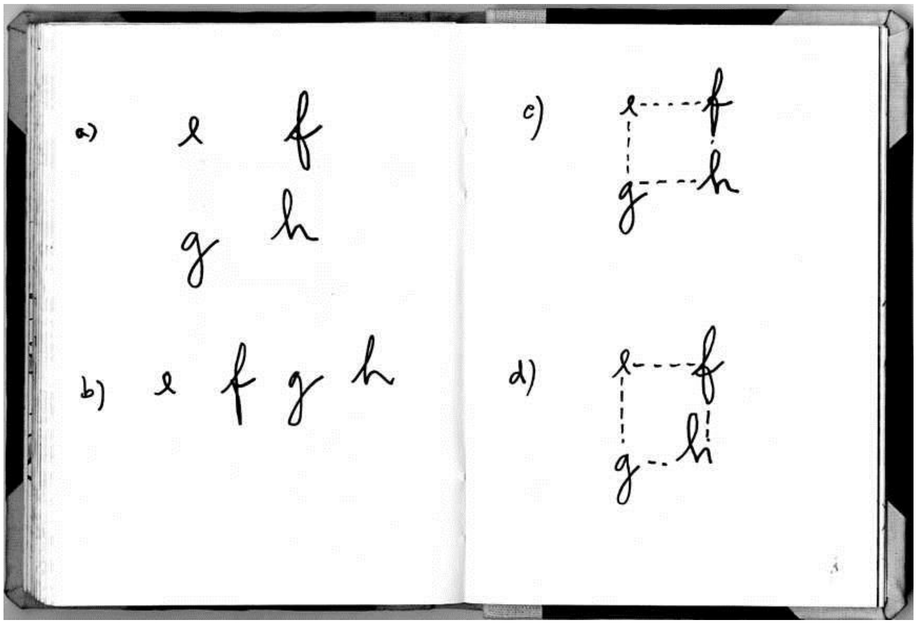


FIGURE 12 OBSERVATION DRAWING EXERCISE (AUTHOR'S DRAWING)

I draw on the board four letters e, f, g, h organized as in a) and I ask the students to copy them. Almost 99% of the students copy the letters in a horizontal sequence as shown in b). Some, very rarely, copy the hidden "square" as in c). To these, although praising them for they cunning instinct for observation drawing, I stress the fact that the original square was not perfectly aligned between f and h, as shown in d).

The students "know" the graphic signs as letters being part of a long memorized sequence of the alphabet so they react in writing mode. The "moral" of the story is that, as drawings, the letters mean nothing as letters. Both writing and drawing are developed abstractly but within different sets of laws. The process of observation drawing must be developed removing any meaning from reality so that an abstract image may be formed between reality and the drawing. Only then the drawing is able to be executed by copying the abstract image.

Every drawing handbook will ask us to see in a different way from the usual one in order to abstractly produce images to be understood as "realistic". At least since Ruskin's "The Elements of Drawing" in 1857 to the recent John Torreano's (2007) "Drawing by Seeing, Using Gestalt Perception" or Sarah Simblet's (2005) "The Drawing Book" not to mention Betty Edwards' (1982) "Drawing on the Right Side of the Brain", there were published exhortations to pay attention to abstract elements or to use abstract strategies while drawing.

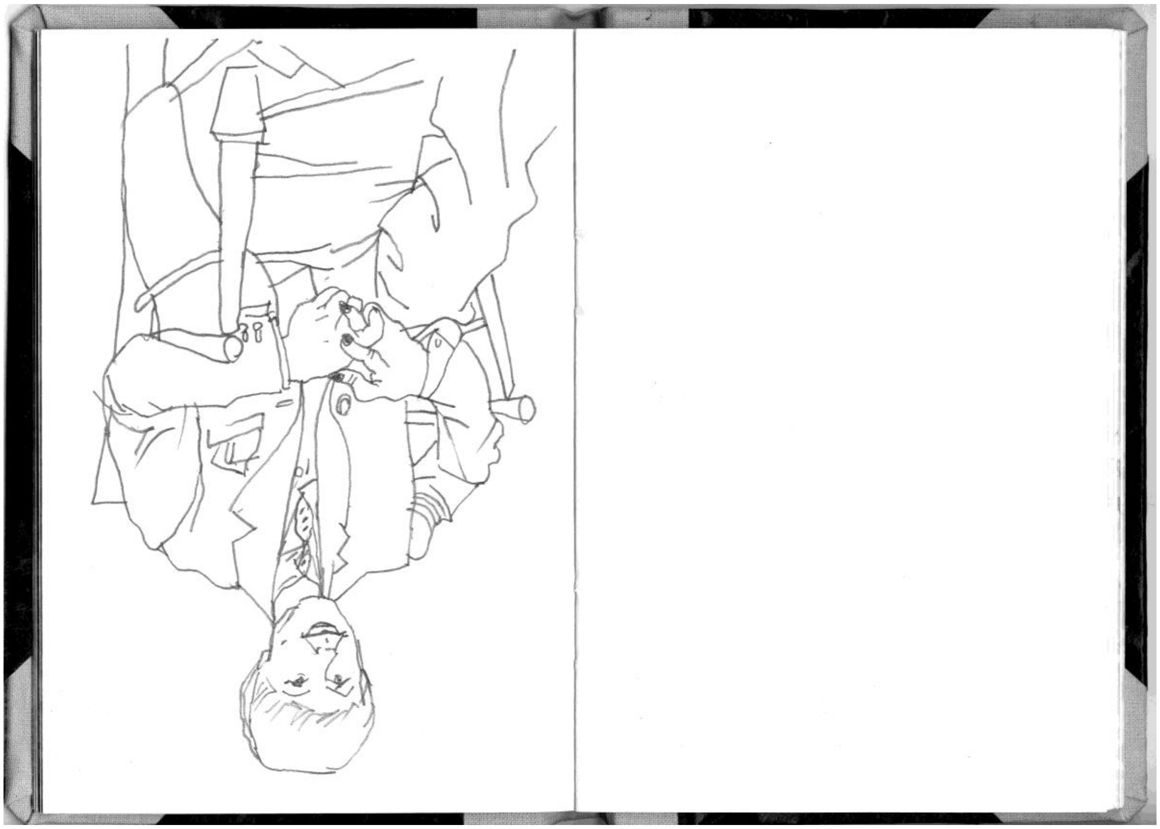


FIG.12. BETTY EDWARDS ALSO DRESSED AS STRAVINSKY IN THE EARLY 1970'S. AUTHOR'S DRAWING, AUGUST 2012

So when we draw from observation we know that the best procedures demand that every element must be drawn abstractly and seen abstractly in reality. That's the way we produce an image to depict.

So let me now summarize two ideas related with knowing in drawing:

- In a drawing anything looks like something.
- While drawing, everything looks (or should look) like nothing.

What we must stress is that even if there are physiological or neural reasons for these two ideas they are not imaginable without a cultural setting. We can even risk stating that much of our culture relies on the first. Let's go back to Einstein, Euclid and Picasso.

Euclid promoted a description of space as an entity where other entities could happen endlessly. From non-existing entities such as three points he invented a plausible universe made of lines, surfaces and consequently volumes. Its practical applications spanned to our days enhanced by Alberti, Descartes and Gaspard Monge. Although we know that space is really what Einstein described by mathematical formulas, our experiential space is closer to Euclid. For instance, we need special conditions and powerful instruments to see light being bent and measure it. In fact, most of our experience depends on light that moves straight. However, Picasso bent it…

SO WHAT DO I KNOW? (DO I KNOW WHAT DRAWINGS ARE, AT LEAST?)

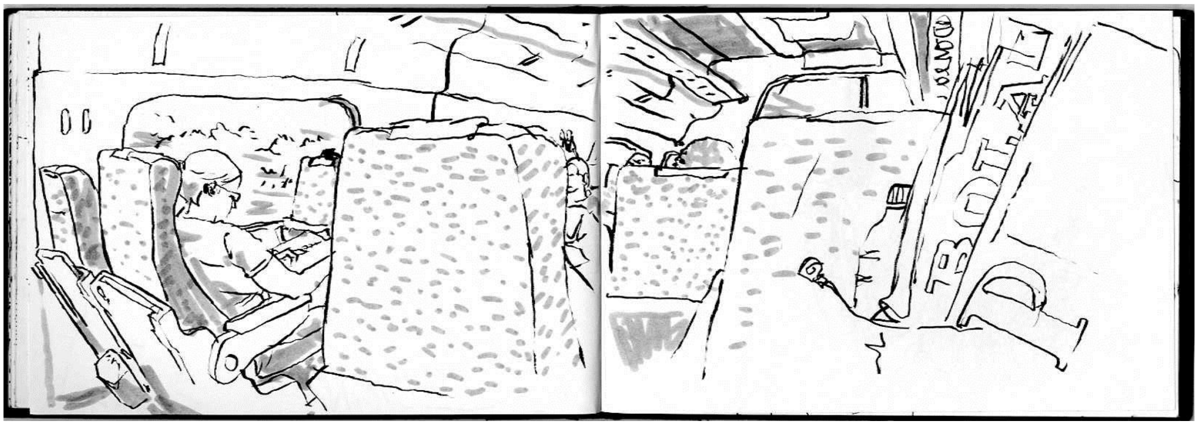


FIG.13. TRAIN DRAWING. AUTHOR'S DRAWING CONTROLLING TRAIN MOVEMENTS. TRAIN BETWEEN OPORTO AND LISBON, JULY 2012

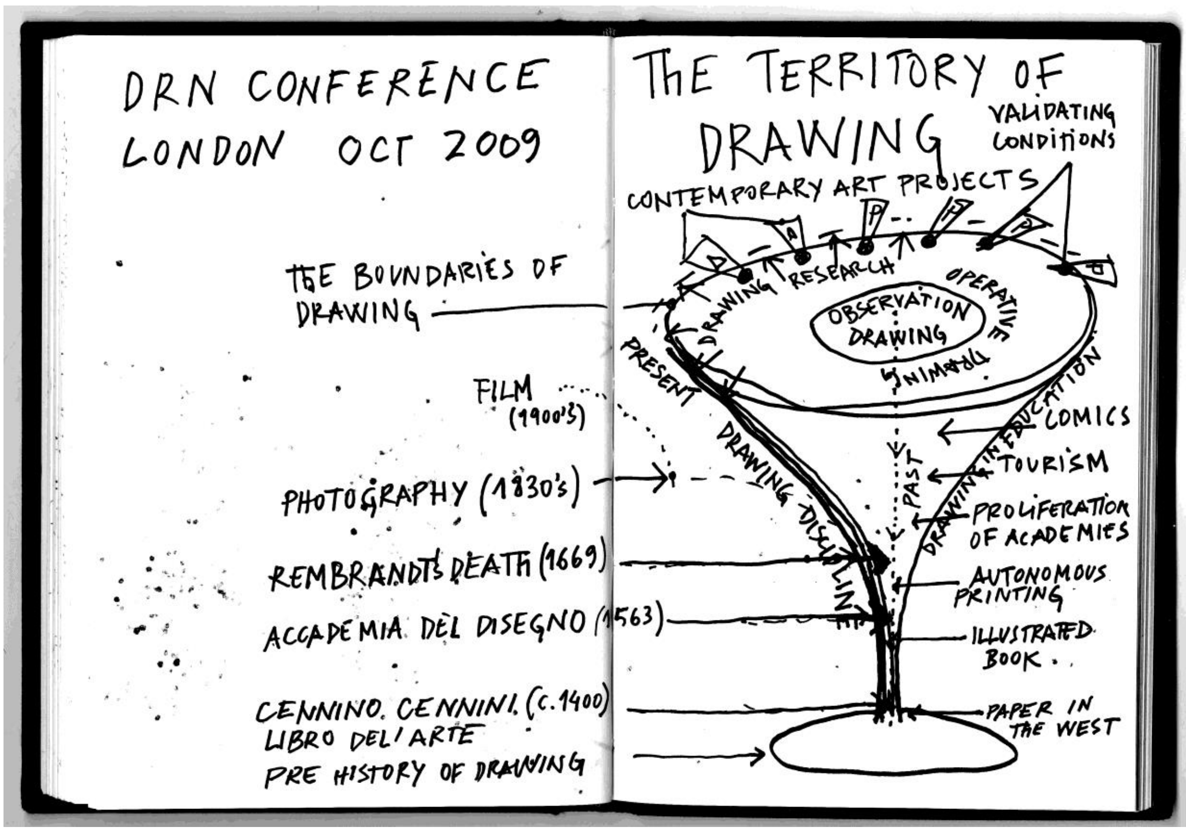
Contemporary art practice enlarged the territory of drawing immensely by using the inquisitive nature of art about boundaries of definitions. As we can see for instance in MoMa´s exhibitions and books "Drawing from the Modern" by Jordan Kantor (2005), in Tracey's "Drawing Now, Between the Lines of Contemporary Art" (2009), and especially in the project run by Teresa Carneiro (2008) in Lisbon, Drawing Spaces, a constant testing of limits inherent to art continuously expands the territory of drawing. These objects, always in the fringe of what we call drawing, possess what I call "at least one validating condition". These works of art, although not essentially drawings had at least one validating condition common to the so called normal drawings. To this endeavor (searching for strange objects and practices in the limits of drawing) we can call "drawing research" because it expands drawing's territory creating new fields or even new facts as drawing. This gave and is still giving authority to drawing inside the university as well as in general art theory. In these settings we can ask what could be the place for the discipline of observational drawing and what its research importance would be.

For now, let me postulate that observational drawing is in the centre of drawing research territory. Accepting this, our resulting question may therefore be "Why?"

There are, of course, historical reasons: the praise of Italian Art, the divinization of Leonardo and Michelangelo related to epidemic of Academies' throughout the western world, not forgetting a general dissemination of printed media.

Engraving and printing gave Drawing the possibility of immensely widening its influence in the representational paradigm of intellectual perceiving of images constituting the basis for modern western visual culture. No wonder that Niépce would open a bottle of champagne after obtaining a blur (with no colour) greyish image of his window. The evidence of so many pre photography devices such as the camera Obscura or the camera lucida can only suggest that Niépce's joy by obtaining a drawing made by light (a photo-graphy) was resulting from the continuing desire to register graphically the observable as described by Martin Kemp (1990: 167-219). But these drawings made by the light had gone far and created a new realm to be developed. The absence of gesture and stenography placed photography outside the territory of drawing. Nevertheless the fact is that both shared a representational nature and the power to depict.

The development of artificial imagery was fuelled by drawing that may be represented if we do historical research about it using a martini glass model presented first in the Drawing Research Network conference in 2009.



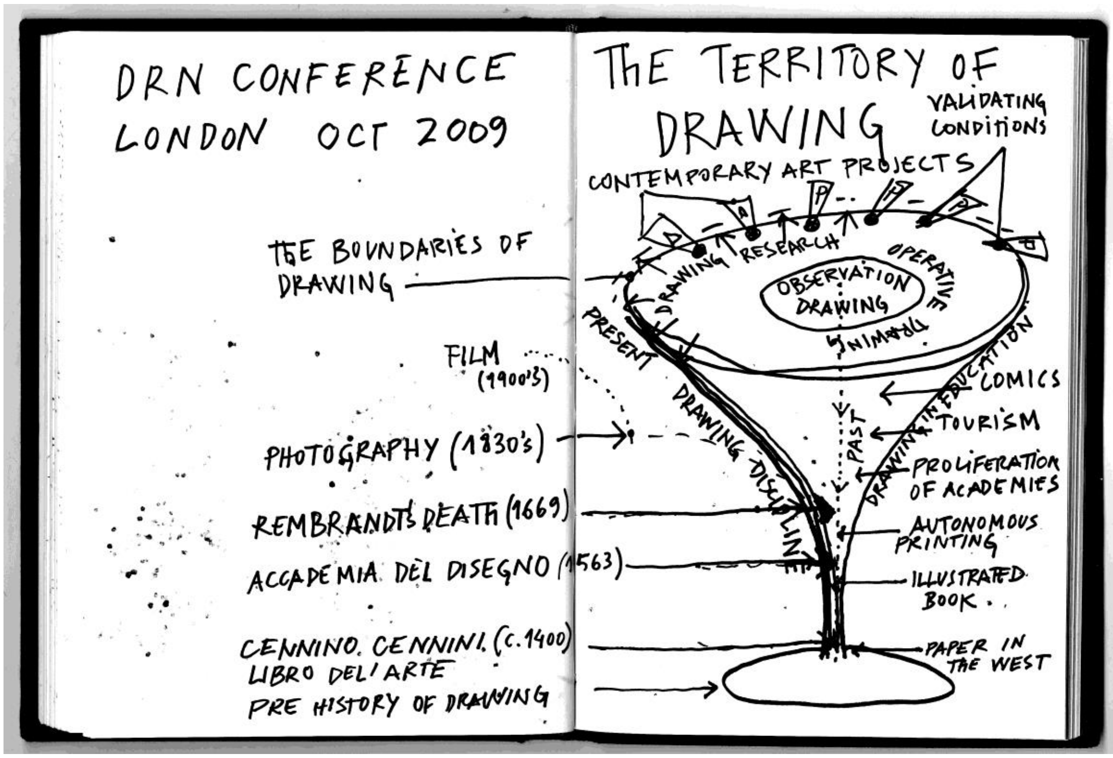


FIG. 14. MARTINI GLASS DRAWING RESEARCH MODEL, AUTHOR'S SKETCH, LONDON OCTOBER 2009

Yet my interest ley upon defining a core for observational drawing. It seemed that I could define a type of drawing more refined as drawing: A purposeless drawing.

A drawing so drawing that could be absent of producing knowledge. The drawings I constantly do and publish aim to achieve this neutrality. This would put immediately my drawing strategy out of the territory that I have defined as the place of drawing research. I must call here Steve Garner when he very wisely wrote:

> *"It seems the distinction between research and practice is healthily blurred. In developing the knowledge base of drawing research we need to draw on writings; there's a lot of valuable reflection out there in books and journals that form a very suitable foundation. We also need to write on drawings; we need to make a contribution to this knowledge base through articulating our work, studies and opinions." (Garner 2008: 25)*

For any observer, my drawings are drawings with no doubt (Figs. 1, 5, 13, 15). Writing about what goes on when doing it seems to be inside "work, studies and opinion". Other disciplines have produced similar self-observations, if you recall Einstein's response to Hadamard.

Whilst the insidious idea that what I have being doing is mathematical, find its way inside my mind, I will still continue to move as a flaneur inside a relativity theory that states we can relatively obtain not only joy as the essence of drawing as Clive Dilnot (2009: 38) affirmed in "The Smooth Guide to Travel Drawing", but also absolute drawings.

So in conclusion what do we know when doing observational drawing?

We know how to set an observation device.

We know how isolate what to be observed.

We know to use time and concentrate

We know about geometry of vision.

We know how to make a cultural translation through a visual stenography.

We know to use gesture.

We know that anything in a drawing will look like something.

We know that the process of drawing is abstract and has its laws.

And finally

When we are doing an observational drawing, at least we know that we are drawing.

FIG. 15. LEMONADE AT JARDIM DAS AMOREIRAS. AUTHOR'S SKETCH, LISBON JULY 2012

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LATERALITY REVIEWED: A COMMENTARY ON A SERIES OF DRAWING AND WRITING EXPERIMENTS IN RELATION TO IAIN MCGILCHRIST'S RESEARCH ON HEMISPHERIC LATERALISATION

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Drawing is a universe - generous, pliable, amenable and able to speak for itself. The author's PhD project, *Design Leads* (2012), addressed how design students conveyed 'supra-rational' modes of practice (intuitive, tacit, material and so forth) through drawing. The research asked: what did experiments in drawing and writing, performed within a group context, reveal about rhythms of design practice? And how might such drawing-designing modes impact on writing practices? This summary describes those rhythms of practice and the correlation with McGilchrist's picture of 'right hemisphere' behaviour. It continues with examples of drawings and writings produced.

INTRODUCTION

My doctoral study, Design Leads, came about through involvement in the Writing Purposefully in Art and Design (PAD) network. Although aware of the rational sphere of design practice, I made a decision to investigate the 'lateral' or 'supra-rational' sphere of designing of contemporary design students' practices (undergraduate and postgraduate) across disciplines. This was motivated in part by a particular conflict: certain strengths across design disciplines (intuitive, tacit, visual, spatial) seemed to run counter to orthodox academic writing strengths (analytical, argument-based, referenced).

In a first phase of research, 38 interviewees - design students, tutors, and designers, armed with objects, photos, screens and sketch books, were asked about their own design thinking and making. This led through narrative review to a loose bundle of 24 main themes of 'lateral leanings', as shown below.

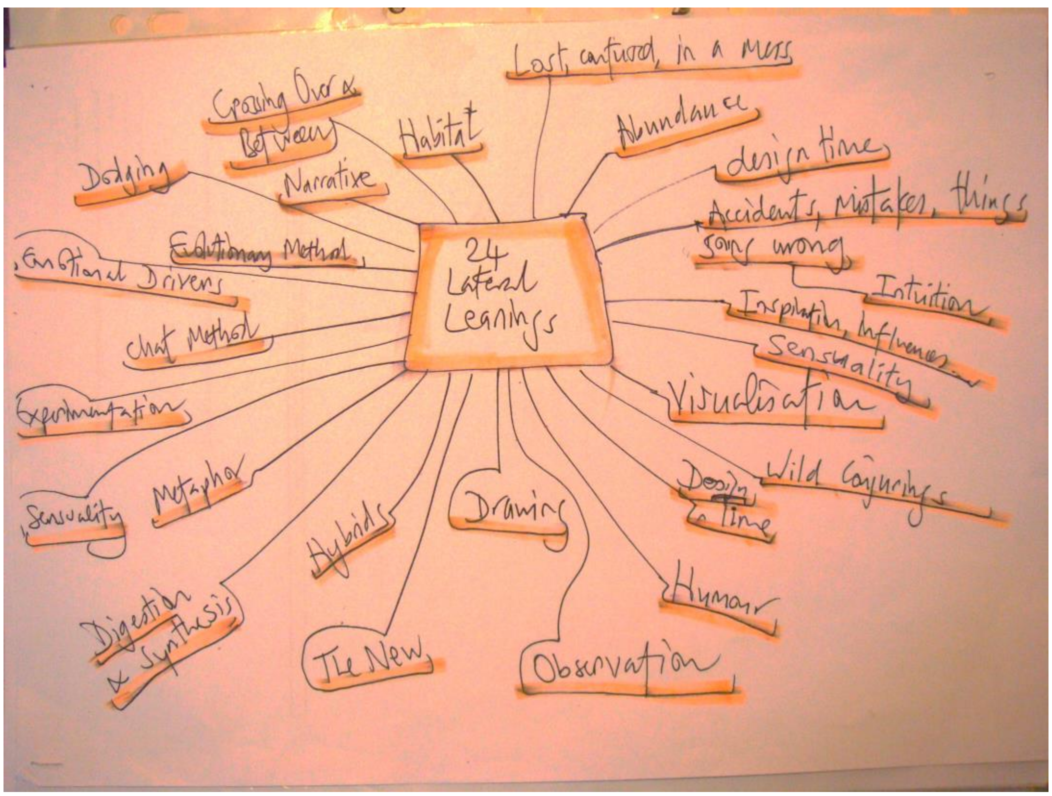

FIGURE 1: LATERAL LEANINGS THEMES DERIVED FROM STAGE ONE: INTERVIEWS

Earlier interests in drawing and kinds of lateral thinking and making had been informed by the likes of Edward de Bono (1967), Arnheim (1969), McKim (1972), Tony Buzan (1974), Betty Edwards (1979), Blakeslee (1980). However, this research appeared superseded by an 80s/90s CAD rise; further research in neuroscience, and then the digital revolution of the last decade, parallel to the promotion of drawing's role in research (Duff and Davies, 2005; 2008).

I began my own research, nevertheless, with a re-view of laterality manifested in the students' design practices: the inclination or 'Leanings' towards the peripheral, subconscious gaps, leaps, jokes, and surreal juxtapositions. I also considered an expanded view of laterality as 'on the margins' or in other words, tendencies I witnessed in students to follow up oblique angles, focus in on what had been overlooked, and further, to break with the mainstream in speculative and exploratory ways. I carried out this re-evaluation out of personal bias as well as from an understanding that such strengths appeared inimical to academic writing practice strengths: I wanted to interrogate such a difference. Two qualifications are needed: these practice moves did not necessarily give rise to hugely original works, of course, although they formed part of regular creative behaviour, and secondly, they were as much a part of design training as of natural curiosity or desire for the new.

The name of 'Lateral Leanings' for such design moves was formalised during the interview stage with design students and staff, and it has remained the title of that early chapter. However, the title could not fully encompass the total experience of the thinking and making recorded, and at some point in the second stage of research during the experiments, the title of 'Rhythms of Practice' seemed fuller and more appropriate, and therefore superseded 'Lateral Leanings', as will be explained.

In the second stage of research, I made a decision to involve drawing and visualisation as tools for expression and generation across design disciplines. This was an opportunity to push research further, and to adopt a participant-observer role. How might this 'supra-rational' sphere of designing manifest in drawing, and secondly, how might it impact on writing practice, and not the other way around?

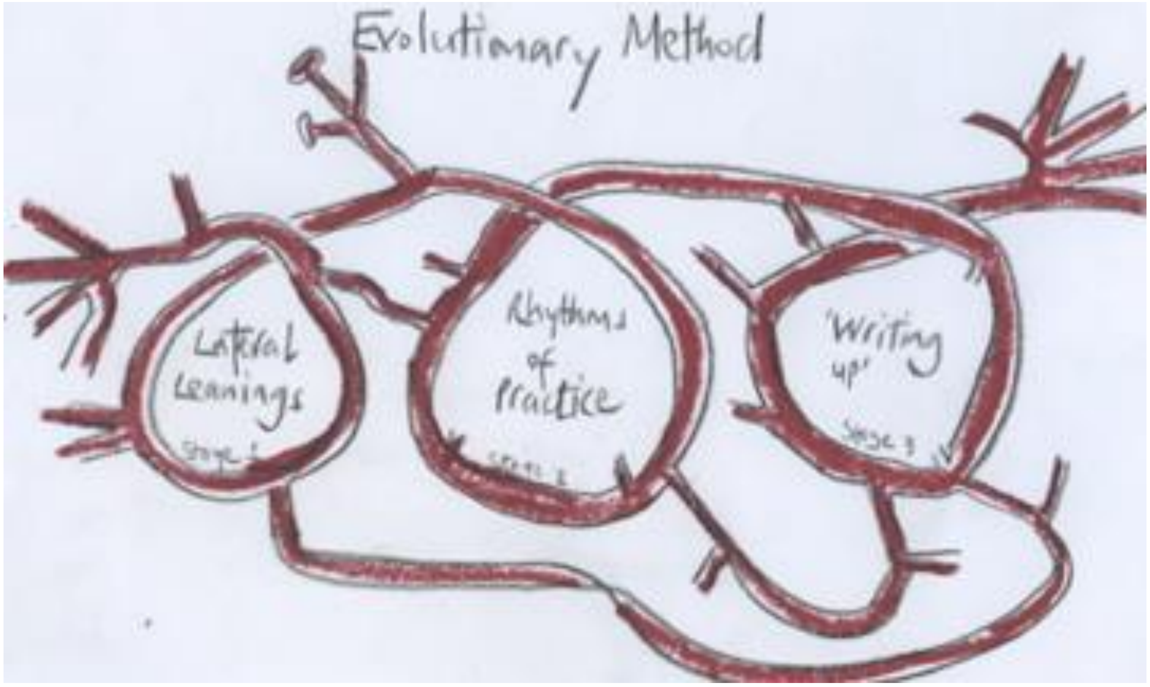

FIGURE 2: THE EVOLUTIONARY RESEARCH PATH WITH MAIN STAGES

This article proceeds with The Rhythms of Practice described; how the above coincides with the picture of the 'right hemisphere' as described by Iain McGilchrist (2009), and finally, some examples of such drawing-designing impacts on writing practice.

1. THE PICTURE OF THE RHYTHMS OF PRACTICE DESCRIBED

Experiments across six *Writing PAD* member institutions involved largely design students (design products, visual communications, fashion and textiles, applied arts) and mostly postgraduates. In the drawing experiments we went for abrupt, raw, first drawing outputs. These were sketches, diagrams, maps, cartoons; records at times that mapped out practice patterns; sometimes ideational or visualisations, and occasionally blanks. Each one centred on a core theme that had been identified through Lateral Leanings (see map above). The individual drawings were followed by informal exchanges around them: what came up? What did it relate to? How was the experience? And so on. Writing followed on. In 2010, after the experiments, I spent another year reflecting back, overviewing research sources and writing up findings. Next, some of the main findings of experiments are recorded, minus the impact of 'Chat' which, although significant within the whole, is omitted due to limits of space.

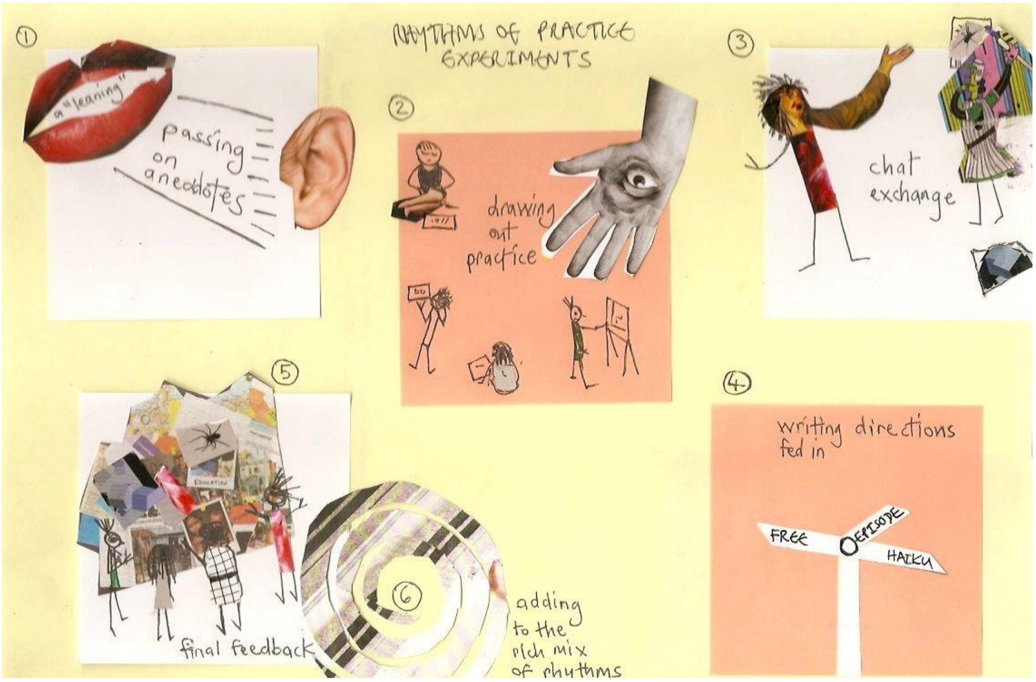

FIGURE 3: A PICTURE OF THE RHYTHMS OF PRACTICE

1.1 SPACE AND AFFECT

First of all, the drawing-centred nature of the experiments appeared inseparable from the effects of the spaces, most possessing the ethos of the studio in the sense of literal marks and tools of practices, a certain looseness, informality and a relaxed mode. There was generally space for participants to spread out and elude a more formal lecture arrangement as well as elude the more private space of an individual studio.

1.2 FREEDOM AND SPONTANEITY

Within the constraints of time and the imposed theme, considerable freedom and spontaneity were exercised. Participants were largely able to move around a space, one that was actual rather than virtual. They worked on the floor, on the wall, on a table, in a corner, with different sizes, scales and shifts of materials and media. They worked fast or slowly or paused.

1.3 DRAWING AND FOUND RESOURCES

Drawing was carried out with all kinds of stuff: the stains that marked the heart of a contour map in Evolutionary Method, and the fold that led the way for a participant in Wild Conjurings. Apart from papers and pencils, graphite, pastels and so forth, there were smudges and marks, stains, as well as paper's own tearability and textile quality, forming a mountain scape in Intuition; subtlety also as in tracing paper employed as a veil over a sonogram in Emotional Drivers.

1.4 PARTICIPANTS' OPENNESS TO MATERIAL

I initially underestimated the resource of material itself that 'came to' participants: they were not just imposing their own will on stuff but open to receiving designs from stuff itself. The facility to pick up on and creatively mobilise the incidental (random, serendipitous) also marked the experiments.

1.5 THE PHYSICAL AND KINETIC

To flexibility and variety was added a sense of a 3D shared space, the physical and the kinetic. For instance, one participant worked with her body on the paper while another started to shift from 2D to 3D realisation in a corner of the space.

1.6 FOCUS AND ATTENTION

The experiments gave rise to a peculiar focus and attention. Drawing seemed to attract a special degree of concentration and absorption. This is hard to prove, easier to witness, or record in log accounts of quietness in the room, sounds of paper, marks being made.

1.7 COMMUNITY SENSE

A sense of community was quickly generated through the possibility of work in real time that could be viewed and discussed by all. The space meant participants could interact easily with each other as well as see each other's work.

1.8 CHARGED EXPERIENCE

Experiences were charged at times, perhaps from the immediacy of the activities and affective responses to them as well as the nature of the themes themselves - the novelty impact of drawing modes of practice.

1.9 HUMOUR

In approaches, drawings and accounts of them, there was a strong humorous element, helping participants to overcome awkwardness, look at mistakes, laugh with irony at their own behaviours. The mistakes themselves were examined and brought into play.

1.10 THE IMMEDIATE PRESENT

In the drawing activity, it was as if there was a clearing of space, to begin with a mental tabula rasa, analogous to the acting context of The Empty Space (Peter Brook, 1966). It required a readiness and ability to be, work and respond in the present: something described also in terms of Gestalt by Mann (2010). The creation of the new from what already existed resonated with the drawing experiments: ‘the figure emerges from an undifferentiated background of experience out of which focused needs and interests surface.’ (Mann, 2010, p.12). In experiments, there was often - though not always - a sense of some raw material emerging that we could then see and explore.

1.11 SOME FRUITFUL INCIDENTS

Drawing sometimes gave rise to fruitful visualisations, insights, and potential directions, with a lateral overriding of steps and deliberation or conscious summing up of ways to go.

2. HOW THIS PICTURE COINCIDES WITH THE PICTURE OF THE ‘RIGHT HEMISPHERE’ AS DESCRIBED BY IAIN MCGILCHRIST (2009)

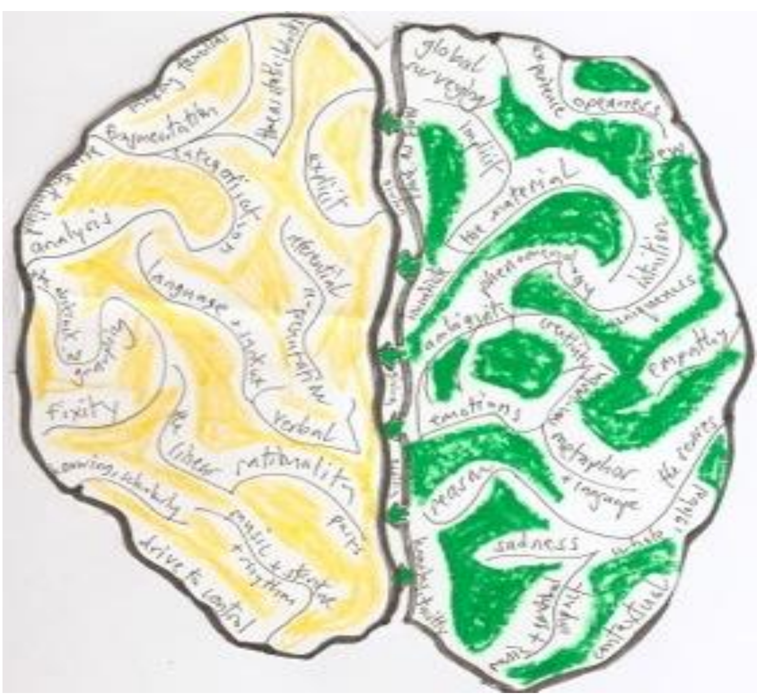

FIGURE 4: A COINCIDENCE WITH MCGILCHRIST’S RIGHT AND LEFT HEMISPHERE

At the stage of writing up, I encountered 'The Master and His Emissary: the divided brain and the making of the western world' written by McGilchrist (2009), and discovered a surprisingly strong correlation between the 'supra-rational' of the Rhythms of Practice drawing experiments and key characteristics of the right hemisphere of the brain, as summarised below. First, a few words about Iain McGilchrist's research.

In brief, Iain McGilchrist's research is based on twenty years of investigation and neurological evidence, particularly of split-brain patients. While he acknowledges the functioning of the brain is more complex than thought thirty years ago, and that the left and right hemisphere (LH and RH) inevitably share much experience, he argues that they do have distinct and complementary roles, and that the corpus callosum is there in one sense to see that they do remain independent from each other. He takes the evolutionary need for survival and sees it in two ways, employing the activities of birds in symbolic manner: those that fly far and wide looking for new opportunities or dangers (RH), and those grounded and intent on the nature and potential of the immediate environment (LH). In fact, his book ranges widely over many cultural episodes as well as very specific examples of individual human behaviour but ultimately, it serves to reinforce the older notion that the right hemisphere of the brain is not only the more creative but the primary one. His argument goes on to relate how the RH, at the symbolic level of the historical, cultural and political, has been usurped in the West by the LH, in a reversal of what he considers to be the proper roles of 'master' and 'emissary'.

In this section, I illustrate central connections between 'Rhythms of Practice' and the views of Iain McGilchrist on the RH before turning to a third section that addresses writing practice.

2.1 A PRIMAL AND GLOBAL WAY OF SEEING

The visual is considered primary by McGilchrist and at the heart of the business of the RH. He sees the RH as paying 'attention to the global picture' (the bird in flight, observing far and wide), and argues that the RH's 'wider breadth of attention allows creativity to come through' (2010, p33). This is reminiscent of interview material, and characteristics of design thinking and making manifested in Design Leads: the proliferation of ideas along with the wide range of influences with which students juggled at earlier stages of making, and that linked in turn to the arduous task some spoke of when attempting to select down.

Secondly, in terms of the drawing activities, there is a tendency to portray whole environments – a mountain scape, a cartoon 'portfolio' of designs, a set of future time scenes, a street scene, a room full of stuff, as illustrated from the drawings below.

2.2 FREEDOM AND SPONTANEITY

In addition to the primary, global and peripheral, there is the notion of simultaneity, reminiscent of Arnheim's view (1969). Sight for McGilchrist is associated with the simultaneous (RH) whereas words are associated with the sequential (LH). There is a link here with those images drawn fast in the experiments that convey a totality, some kind of whole, as described above. Part of the strong impact seemed to be the way that things appeared suddenly, with the action of the hand conveying the thinking, before deliberation or reflection.

2.3 EMBRACE OF EXPERIENCE

For Iain McGilchrist, the LH is very much to do with control of our environment a part of which is grasping things and getting to know them very well (as in the bird paying attention to its immediate environment). In contrast, things are continually new for the RH. The novel attraction generated by the experiments comes to mind at this point: the willingness to have a go and the intrigue about what the experiments were about. In addition, whether or not the outcomes of the design thinking and making were actually original, there was a drive for the new (a sense of newness for each participant) in these attempts.

2.4 LATERAL ARRIVAL

The understanding in Design Leads of 'Lateral Leanings' that is, the kinds of thinking that seemed to come in 'at the side' is analogous, I suggest, to the appearance of the new and how Iain McGilchrist perceives it:

> *'…in almost every case, what is new must first be present in the right hemisphere before it can come into focus for the left. For one thing, the right hemisphere alone attends to the peripheral field of vision from which new experience tends to come; only the right hemisphere can direct attention to what comes to us from the edges of our awareness, regardless of side' (2010: 40).*

FIGURE 5: MOUNTAINSCAPE

FIGURE 6: PORTFOLIO OF DESIGNS

FIGURE 7: FUTURE TIME SCENES

2.5 THE SENSORY AND THE MATERIAL

The Senses and the material also form a strong part of Rhythms of Practice. The experimenters' interaction with them was not intellectual but intelligent: enquiring, multi-modal, multi-dimensional. The earlier 'Lateral Leanings' title could not encompass such breadth; hence the change to Rhythms of Practice. The Wild Conjurings experiment drawings bore witness to a closely related difference in RH and LH: drawings revealed the participants' grip on the present in contrast to my own more conceptual or surreal fantasy of the future. McGilchrist also pointed out such a difference: that between a kind of mental imposing on something (more LH) and that of a contrasting receptivity, permissive of seeing what is actually there before the eyes, or less framed in other words by pre-prepared narratives in the head.

FIGURE 8: SENSORY AND MATERIAL MOVES

2.6 MOVEMENT

In all of these above, the quest for the new, the experiential, the sensory and the relating between, there is a sense of movement. McGilchrist picks up the Heraclitan notion of flow to describe the workings of the RH (2010: 30): 'Experience is forever in motion, ramifying and unpredictable.' It brings to mind the etymology of 'emotion' as moving out. It is reminiscent of the movement of bodies working in the spaces themselves; of the movement of ideas that passed around the groups, and the speed at which the drawing seemed to provide momentum. All of these examples point to rhythms and the dynamism of the experiments that prompted the name of 'Rhythms of Practice'.

FIGURE 9: RHYTHMS AND DYNAMISM

2.7 SHIFTS AND EMBODIMENT

About attempting to move from a sphere of material practice to one of PhD research, one participant said, 'how do you get that [research reading] into a form? … In a way it's about um a message that's constantly altering and moving.' In experiments, it appeared that affect (frustration and humour, intrigue) went together with searching for an embodiment – loosely, a designing solution. The drawing made by the same experimenter was of a multitude of shoes, ships, transport:

> *'I drew lots of different forms of transport (laugh). I was thinking of vehicles and movement and … I did a lorry, a bike, an aeroplane, a steam train, … a tanker, a container ship (laughter) and then er, a push chair. I don't know, maybe a wheelchair. Em, and shoes. Yea.'*

This search for translating and moving was light-hearted but not trivial. The drawing touched on a sustained research problem that went beyond the experiments. It evokes the strain between visual and word: one more concrete, immediate and one more remote; one more holistic and simultaneous, the other more detached and sequential. We might describe this particular drawing-encounter as an emotional tension between RH and LH.

2.8 METAPHORIC LAYERS AND AMBIGUITY

In addition, Iain McGilchrist says that the RH, in a corollary to keeping options open and not fixing things, insists on the implicit. There is, for instance, a leaning towards Metaphor, with its power to hold various layers of meaning together and sustain ambiguity. Within experiment examples, there is an interesting diversion from this statement by McGilchrist. An object that was drawn might evoke a variety of interpretations of meaning, but the participant who made the specific drawing often supplied a detailed context for it - from memory. And in line with the rationale for the experiments, the memories would then be absorbed into design practices, part of the making. And in design practice, there would be a commitment to an end point, with the vague, apprehended and multi-layered subsumed eventually, perhaps equivalent to the move to an LH sphere.

In retrospect, the drawings - full of *thing*s – were not categorically Metaphor but rather what 'came to' participants (their language), from the mind's eye or the immediate environment. They were generated through drawing, and then talked around, taken for granted, but not especially analysed because of their metaphoric ability to hold subtle levels of meaning together, as might have taken place in a more academic context.

2.9. LANGUAGE

The RH 'cannot have certainty of knowledge that comes from being able to fix things and isolate them. It does not form abstractions and categories that are based on abstraction that are the strengths of denotative language. [...] the right hemisphere interest in language lies in all the things that help to take it beyond the limiting effects of denotation to connotation: it acknowledges the importance of ambiguity. It therefore is virtually silent, relatively shifting and uncertain, where the left hemisphere by contrast, may be unreasonably, even stubbornly, convinced of its own correctness' (2010: 79-80).

It is impossible to say whether a reluctance of participants to write at times was due to previous negative educational experience; not knowing how to proceed, or to a wish to defer in order to have more time to digest and absorb. Whatever the case, Iain McGilchrist's picture above made considerable sense when applied to the educational context I found myself in, as mentioned in the third section.

2.10 IN SUM

Overall, Rhythms of Practice experiments show many RH tendencies. RH 'global viewing' coincides with the theme or 'lead' of Observation, for some in this study, a calculated practice while for others, an obsession, like an instinct. And in that global viewing, we find an obsession too with The New, both in the attraction to what is novel and seeking out the new. The openness required for perceiving the new is prepared for by a special attention, a readiness to receive; Abundance is the result of readiness, obsession and seeking out.

Closely related to the New is Experimentation, which goes with curiosity, taking a risk, with uncertain outcomes. Hence the relation to Accidents and Mistakes and to Lost, Confused and in a Mess. The latter Rhythms are not always positive; sometimes they remain simply frustrating. Whether or not such Rhythms bring insights, the experimenters' approach was adventurous and the experiment matters were seen as opportunities, difficulties to work through, or material for exploration. And again, the Emotional Drivers pervaded the exploration; not necessarily passionate emotion but connected with intrigue, doubt, some relief, some joy, humour. The experiments exercised the emotions, which exercised the drawings.

In distinction to McGilchrist's much broader sweep of visual culture (amongst related cultures), my small thesis involves the specific 'lead' of Drawing, a valuable design mode that allows the visual to become tangible on the page. The Visualisation and the Drawing are considered central Design Leads, modes of thinking and making. The activity of drawing appeared, in fact, conducive to two contrasting modes: a mode of absorption or concentration yet in contrast, a mode of rapid performance, with a simultaneity that by-passes slower, more methodical routes or possibly the pre-meditated, the conscious mind. Both appear to bring forth a wealth of raw material.

2.11 AND IAIN MCGILCHRIST'S LEFT HEMISPHERE?

> *'By contrast, in order to control or manipulate we need to be able to remove ourselves from certain aspects of experience, and in fact to map the world from the vertical axis…' (McGilchrist, 2010)*

Here is the LH, a more abstracted, remote, categorising sphere that holds a complementary yet secondary place in the scheme of things, or should do. According to McGilchrist, it has usurped the primary role of the right hemisphere. If the view of the RH has usefully illuminated the supra-rational modes of designing in this study, then the LH would seem to share certain characteristics of a more orthodox academic discourse. The potential impact of the supra-rational modes of design on academic writing culture is in part analogous to the potential RH influence on the LH.

3. SOME EXAMPLES OF SUCH DRAWING-DESIGNING IMPACTS ON WRITING PRACTICE

The findings of the research project went some way to underline the sense I had in my educational role of dual spheres: the 'supra-rational' manifested through

designing-drawing and academic writing. If as proposed by Iain McGilchrist, the RH has a stronger propensity to go for the new and to be interested in that, there may be less of an ability to control and to categorise information that requires the opposite propensity, namely to stay with the familiar, with attendant processing. However, the thesis was not based on the incapacities of design students but rather on strengths. How might 'supra-rational' designing modes impact on writing practices? A few examples follow.

3.1 EXAMPLE ONE

FIGURE 10: THE LOST SEASCAPE

> *'I started drawing a safe space and I'm kind of getting out of that safe space and wandering, and getting lost so it's actually it's quite literal, it's not conceptual or abstract.'*

Visualisation is primary thinking that comes fast and through the fluent execution of an image such as the 'Lost' seascape in which we view everything at once in a joining of simultaneity with complexity. The words without the visual appear meagre, solitary, but with the visual, they become part of the 'supra-linguistic' 'lost'-quest – the words are embodied and integrated into a fuller picture. I could apply my LH analytic skills to the image of the lost-scape and articulate a number of patterns of words-shapes-movement-thoughts. But the drawing was produced in some minutes and without hesitation, conscious planning, measuring, scheming or the like. Drawing can offer a full and immediate portrayal of a whole that is totally distinct from a slower, more deliberate step-by-step approach.

3.2 EXAMPLE TWO

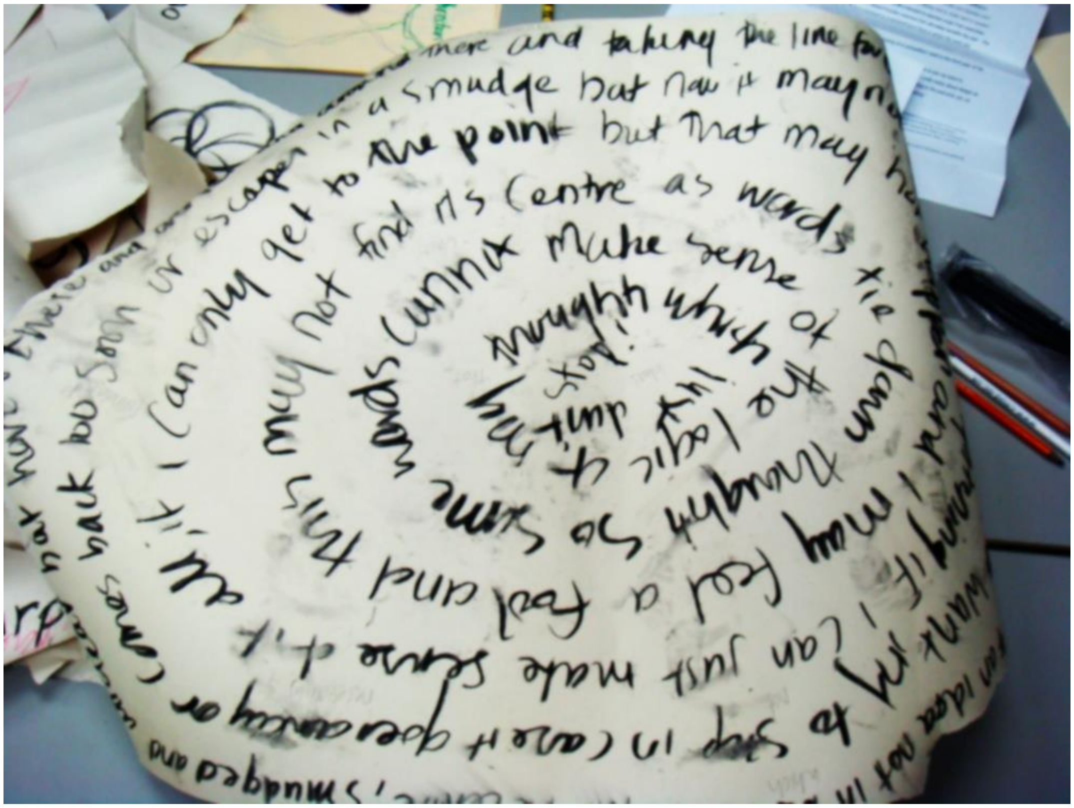

FIGURE 11: IMPLODING SPIRAL OF WORDS

The participant began by saying that she was not comfortable with words. She had made two pieces: the first was writing in a spiral where she commented that the ideas just keep on coming around it though not in a sentence, rather in a loop without end. The second consisted of chunks torn from a roll of paper with words on: had the exasperation descended into disintegration or frustration or anger? These were, ‘not meant to be looked at really’. I inferred they were not in rational, read-able forms but to read visually. Ironically, the participant spoke confidently and fluently about this writing area of which she had profound doubts.

3.3 EXAMPLE THREE

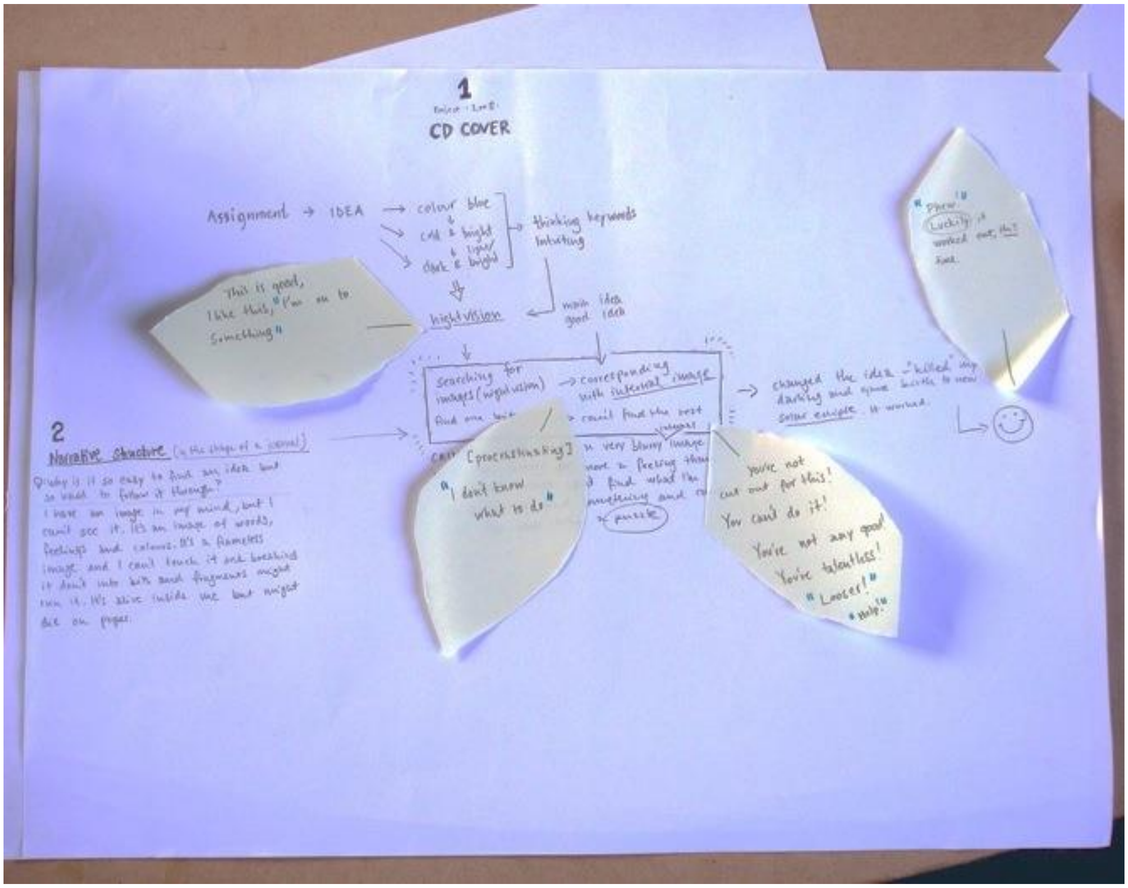

FIGURE 12: CD-COVER AND MISTAKE

Evolutionary Methods, the CD cover, writing after drawing: 'Why is it so easy to have an idea but so hard to follow through? I have an image in my mind, but I can't see it. It's an image of words, feelings and colours. It's a frameless image and I can't touch it and breaking it down into bits and fragments might ruin it. It's alive inside me but might die on paper.'

These comments were written after drawing a process of a previous design that had not been completely successful. Ironically, the writing stage proved a very poetic articulation of the nature of design visualisation pre-words. In terms of the RH and LH relationship, the protected first thoughts are definitely RH, or primary thinking. I imagine such thinking gradually moving to LH for digestion and designing/making; when it passes to writing, it is twice removed from the primary. In contrast to some approaches to academic writing, this implies that vagueness can be a key to the start of a new venture and that an initial fixed position or a rush to be explicit, to plan ahead too much, may be detrimental to this impetus with a more gradual unfolding. How to allow for a space and distance in time and perspective is crucial but extremely difficult when everybody's diary is crammed full and the pressure is on.

A second point: this writing post drawing, apposite for a reflective journal, does not present a transparent solution for the previous CD-design: a solution was reached through the drawing without a conscious explanation. A writing-up cannot always provide a logical reason; on the other hand, it can reference or signpost back to what is primary, I suggest. If this designing example had been placed in a portfolio of writing, there could have been no rational explanation; instead, a record of a drawing, chatting, writing mix that gave rise, *somehow*, to insight.

3.4 EXAMPLE FOUR

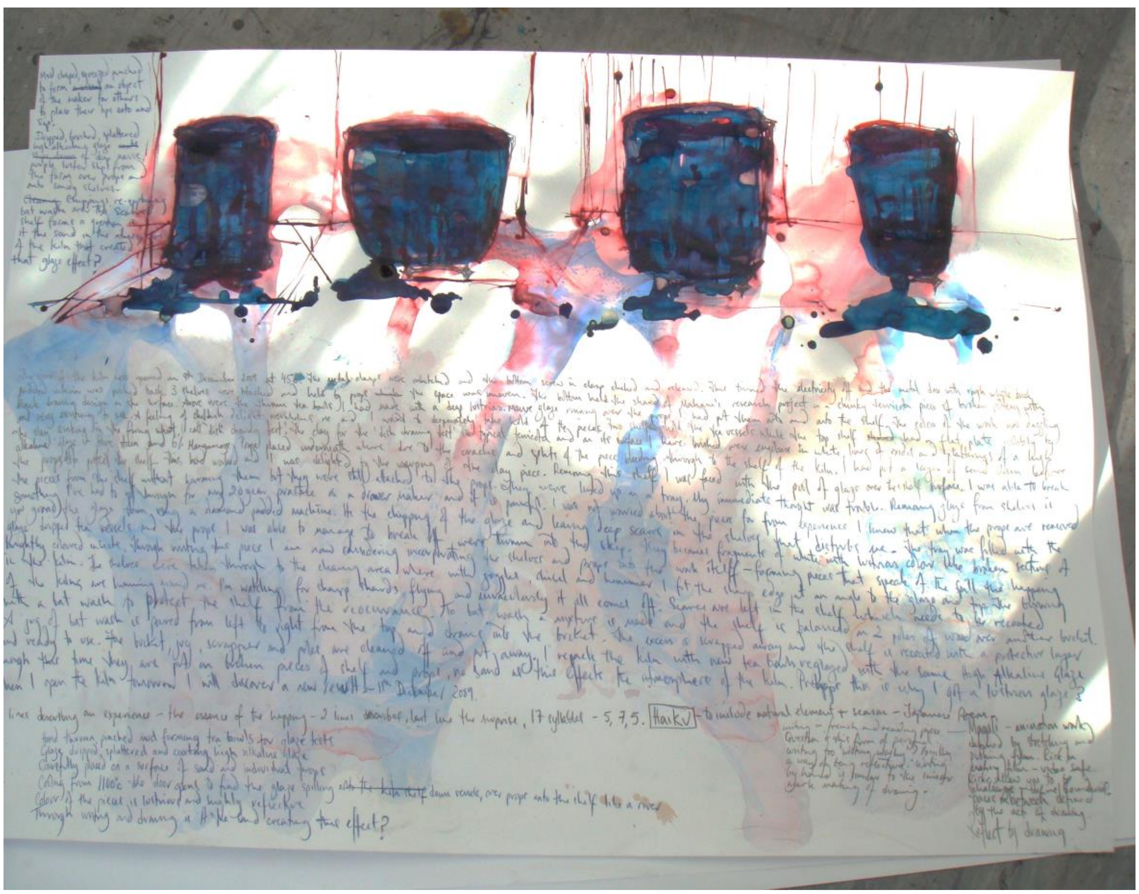

FIGURE 13: CERAMIC ACCIDENT AND REVELATION

> *Spoken extract: A '…but I understand it this time […] which I wouldn't have picked up on if I hadn't done this. Because it's actually the drawing out and having to remember, you know, every single part of that accident of putting it together, to opening it up.*

> *B: To have a mental observation?*
>
> *A: Yea, and that small part of the sand – I'd completely forgotten about until I'd done this exercise…it's fantastic! (laugh) I want to run downstairs and say, 'look at that!'*

Again, the act of drawing-visualisation can bring dynamic insights into previous practice mistakes or accidents, such as in this case of the Ceramics accident, in part a material re-enacting. The reason why is, as above, not completely clear. Partly the allowing of time, space and the non-cerebral approach of drawing that brings up stuff from the sub-conscious? Some of the writing that came from such visualisation shows acute observation of what could otherwise be overlooked. Whether a review of something old or a view of something new, these writing outcomes are valuable in feeding into practice. Visualisation is not rational but extremely valuable in contributing new insights; it is a world apart from an approach that begins with a search for relevant literature (texts, words, linearity) and proceeds to finding a gap in that published material.

3.5 A SENSIBILITY

In the survey of micro-elements of writings after drawing experiments, a sensibility manifested through the concrete, in action, in the direct first person, in lists and changes of focus, explorations of concepts and dynamic opposites. In these ways, the writing characteristics resemble those of the RH of McGilchrist's research, and the opposite of certain LH characteristics – abstract, impersonal, consistent, more fixed, goal-oriented and argument-based, categorising, objective – that in turn bear a strong resemblance to qualities of orthodox, academic writing. The metaphors of hand held out and hand tightly grasping (RH and LH, I would suggest), as articulated by Terry Rosenberg's writing on ideational drawing practice (2008).

3.6 CONDITIONS OF WRITING – AN ECOLOGY

I include a map of what might be called the conditions of writing from drawing experiments, with some debt here more generally to phenomenology and the experiential, and more specifically, to Graeme Harper looking at the conditions for creative writing practices in 'On Creative Writing' (2010).

FIGURE 14: AN ECOLOGY OF WRITING

3.7 A RANGE OF RESPONSES

The experiments specifically constructed to allow a 'supra-rational' emphasis produced the following range of responses to writing:

- The first response might be not to write at all for numerous reasons: everything in the image, all in the chat, no relevance, a sense of shame, a block, a need for private space or an incubation period.
- The second main response was to write words down but to hide them and employ them as memos, notes to self, for the future, taken up in chat feedback or in performances.
- Then there were words integrated with drawing - in dialogue, cartoon, blurring with shape, space, colour, underlining concepts and emotions; words taken up in experimentation, as well as a variety of other expressive writings that were episodic, observational, poetic, recording insight. Although some of the latter were fed in (maps, recipes, haiku, slow writing or observational) many occurred as a spontaneous and non-mediated response to the theme and the drawing effects.
- There was also some revelatory writing that acted either as a conduit for insight after drawing or simply as a record of the insight that had occurred through drawing.

- Finally various participants declared an interest in pursuing expressive modes of writing and on the basis of experimental outputs, I believe they could do so in all kinds of interesting ways. The major obstruction would be the dearth of time to commit to another practice.

Ultimately, the contributions to writing practices in the thesis were offered as augmentation of what already exists rather than an alternative so I will finish with a map of design writing culture that places some of the experiment writing types in a larger perspective. This includes a proliferation of professional practice writings that merge with postgraduate design studio practices inside and outside institutions. Two reflections on these: firstly, many of the writings have emerged with or because of digital technology, which is surely a ‘naissance’ when things happen so fast they cannot be pinned down or established, and when writings tend to be both short in length and towards speech. Secondly, they tend to be in a multi-modal context. So, while neglecting the impact of the last ten years of the digital here, I can still point to a flux and output of experiments that appear complementary to ‘digital’ opportunities including writings. I suggest this direction pulls further away from the ‘LH’ of orthodox academic writings in an expanding sphere.

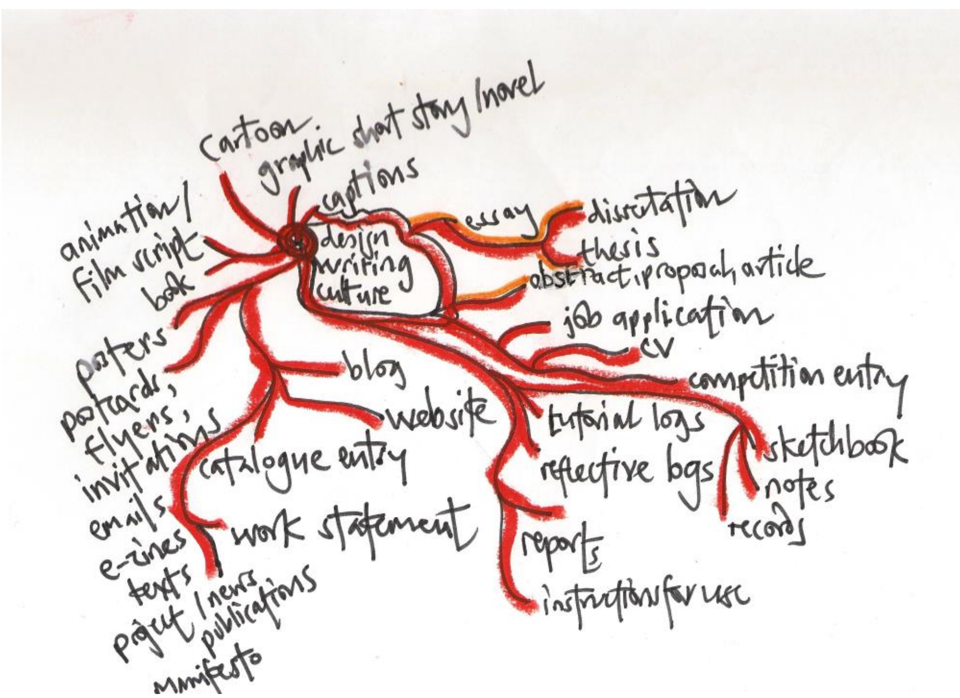

FIGURE 15: WRITING IN DESIGN

CONCLUSION

When comparing the characteristics of the experiment to those of RH/LH in The Master and His Emissary, some clear 'misfits' emerge: the publication speaks of invention and design as being LH, which I would see as an omission of the RH kinds of activity and thinking recorded in the experiments. There is a whole passage on the dominance of LH conceptual art that is derogatory and seems not to take account of the diversity of art and design in UK practices, inside and outside institutions. Further, there are passages on time that do not appear to coincide with experiment findings. What is more, there is a huge generalisation in Iain McGilchrist's thesis that the western world is divided; that the LH sphere has dominated since the Enlightenment, and that this is to the detriment of the RH, and ultimately to us all.

At the end of his book, Iain McGilchrist suggests his RH and LH duality might just come down to a metaphoric split in the way we think and behave: this I find useful, but what is alarming is that I now seem to see the duality everywhere.

Finally, while there is significant correlation between the picture presented by Iain McGilchrist and the outcomes of drawing and the Rhythms of Practice summarised here, there is no neat fit – that would be glib and superficial. It would also be a triumph of 'LH' thinking, imposing a framework and professing a certainty when in fact, there are many questions left and reasons, maybe, to leave some unanswered.

Questions for discussion

1. Is the picture of the Rhythms of Practice derived from experiments recognisable to others in design practices? To research students and tutors?
2. Does the coincidence with the 'RH' and 'LH' make sense in some ways, or is it too much of an over-generalising framework? Does the polarisation emphasised by Iain McGilchrist resonate in other ways in the institution, or in society?
3. Does crossing from a practice such as drawing to one of writing take place seamlessly or is it a difficult crossing? Do the two spheres complement each other? Is collaboration between one who draws and one who writes a good route to take? Can drawing provide us with insights and raw material that words cannot?

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A CYCLE OF DRAWING IN RESEARCH INTO LIFE AT THE MOLECULAR LEVEL

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At the nano-scale, our body cells are packed with millions of tiny protein machines, each with a key part to play in human physiology. The understanding of what each protein does and how it interacts with its neighbours is fundamental in keeping us well, fighting disease and designing new, more effective drugs. The more questions we ask, the more complex life at this molecular level appears to be. Despite improving technologies, the practice of drawing remains an integral part of the discovery process, allowing the maker to think through and bring together distinct ideas, analyse protein-protein interactions and plan ways to test hypotheses. In this paper, I discuss how a cycle of drawing is used, with each drawing type feeding forward into the next, and each iteration improving clarity and the collective knowledge. Sketches and drawings made to understand the wider scientific literature inform the planning of experiments and weekly timetables, the results of which feed back to embellish what was initially understood. I identify a trend at all stages of the cycle, where drawings begin life as transient objects, becoming more permanent as the thought contained within them persists. Permanence frequently involves the digitalisation of the drawing, allowing increased viewing through dissemination to the wider community in journal articles and discussion at scientific conferences.

INTRODUCTION

There are an estimated ten trillion cells in the human body, organised into tissues specialised for particular functions. Each tissue or population of cells must carry out its job, such as absorption of nutrients into the body in the case of the small intestine, together with its house-keeping functions of energy production and cell renewal. Just as one member of an orchestra must not play their part without regard for the tune played by their colleagues, a single cell must communicate with neighbouring cells and with cells in other tissues to ensure that they are carrying out their specialised role exactly in line with the needs of the body as a whole. Communication is achieved by the production of small molecule messengers, such as hormones like insulin, adrenaline and cortisol. These are synthesised and secreted on demand, and travel around in the blood, searching for the appropriate target tissue to pass their message on to. A key will only fit into a certain shape of lock; the hormone will only be recognised by a particular receptor found on the surface of its target cell. Binding of the messenger molecule to its cognate receptor sets in motion a series of inter-molecular interactions, which communicate the message into appropriate compartments in the interior of the cell. Any misinterpretation can have disastrous consequences, and it is therefore essential that we understand how these communication pathways operate so that we can find ways to fix them in disease states, including cancer.

Understanding how the protein machines work and interact with one another would be impossible without the use of drawing to aid in the thought process. Drawing enables the thinker to bring together consideration of different scales, from the atomic to the whole tissue and organ level, and to imagine complex processes that are not able to be visualised using microscopy or other imaging methods. The use of drawing as a teaching tool in the classroom is widely acknowledged (Dempsey and Betz, 2001; Driver et al. 1994; Lowe, 1987; Nyachwaya et al. 2011), yet its use as a thinking and communication tool by the researchers themselves has not been reported. In this paper, I discuss the concept of a drawing cycle underpinning all research methods in molecular biology. The first part of the cycle involves placing the research question into context through regard for the wider scientific literature. These drawings inform the next part of the cycle: planning experiments to test hypotheses in light of what is already known. The results of new experiments supplement the existing knowledge, bringing new questions to the forefront, and so too the planning of new experiments. Each stage in the cycle employs the tool of drawing.

THE DRAWING CYCLE IN BIOMOLECULAR RESEARCH

The role of drawing in understanding the wider context

In order to begin to find ways to answer a particular research question, it is imperative that one first has a good understanding of what came before. Put simply, there is no point in repeating work that has already been done. In reading about the research that has been attempted, the scientist might learn methods or important points that they had not thought of, including experiments to be avoided for one reason or another. Scientists report their findings through publication in peer-reviewed journals, through talks and poster presentations at conferences, and discuss methods in online forums. The use of images and diagrams is key in this communication of information. Drawings allow the rapid integration of findings from different sources, and through the use of symbols and accepted jargon can be easily copied and modified as they are passed from one researcher to another. An example drawing is shown in Figure 1A, which is a sketch of a diagram in a review article about signalling pathways in blood platelets. The top part of the drawing describes several pathways by which a signal is transmitted from outside the platelet to the inside though physical interactions, conformational changes and enzymatic reactions. Towards the lower half of the drawing, the portrayal of the signal becomes less detailed, stating instead the wider phenotypic consequences of the interactions.

In all parts of the cycle, drawings begin life with a sense of immediacy, made using whatever tools and surfaces are available to hand. This may be pencil or pen on paper, but may extend to the back of a catalogue, the corner of a newspaper or a napkin. The importance is in getting the idea down quickly before it is forgotten. Often, a quick sketch made during a conversation might aim to establish that two researchers are thinking along the same lines. Dry-wipe markers on a whiteboard might be employed for drawings made in a communal setting, such as during a brain-storming session in a lab meeting (Figure 1B). Here, the scientists have discussed the inter-conversion of members of the phospholipid class of lipid from one form to another, with respect to the location of enzymes required within the cell. The drawing includes hypotheses about unknown connections and how one might target each part by experiment. In general, little care is given to the colours or scale used, and much is gained through the experience of drawing and discussion. Often a change in colour marks a pause in making the drawing (perhaps minutes, hours or more). A new colour might have been picked to introduce new ideas to an existing drawing, or because the original colour has disappeared or expired. In this way, the use of multiple colours might reflect the time taken in the communal thinking process for the evolution of ideas.

These initial drawings have a tendency to be transient in nature: markings on a white board are easily wiped away; a drawing on a scrap piece of paper is easily lost or discarded. A drawing in a notebook or lab book may also be considered transient as it might only be happened upon as long as that book is in use. When that notebook is finished and a new one started, the drawing might only persist if it is re-drawn. A drawing on a whiteboard is less transient than a drawing in a notebook in some ways, since it has the opportunity to be seen constantly by all that pass it. In the same way, a drawing on a piece of scrap paper may be pinned on a wall and remain in the researchers' consciousness until it is covered up or removed. All of these types of drawing may be erased and surpassed by a new drawing or theory. Further modification and refinement is required to prolong its life and ensure it remains in the researchers' thinking. This is frequently achieved using digital methods, which also enable the communication of the thought to the wider scientific community. This dissemination might occur through publication in a journal or grant application for research funds, reproduction on a poster, or in a slide in a talk at a scientific conference.

The use of computer software not only makes a drawing more permanent, but also allows the processing of a large quantity of complex data into dynamic drawings that can be more easily understood and manipulated. This includes complex interaction networks, such as those generated using GeneMANIA interactive software (Mostafavi et al. 2008) (Figure 1C), and the structure of the individual proteins themselves (Figure 2). The protein shown in this latter figure is RdgBβ, which transfers phospholipids between different intracellular membrane compartments. The computation of the positions of individual atoms making up a protein in three-dimensional space is not possible using the human mind alone, and so computers aid us in this task. Software such as the PyMOL Molecular Graphics System allows the rapid rendering of a molecule, permitting the researcher to try different ways of seeing the structure in order to determine the best method for visualisation. The structure can be manipulated in three-dimensional space, which is an essential requirement for understanding and thinking about how these tiny protein machines work. Theories about the importance of particular amino acids in protein-protein interactions or enzyme functions can be formed and later tested by experiment.

The visualisation of protein structure using computer software can feed back into quick, hand-drawn sketches. The X-ray crystal structure of RdgBβ has not been reported to date, and so the protein's amino acid sequence has been modelled on a reported structure of another member of the transfer protein family (Figure 2). RdgBβ is distinct among this family as it carries a long amino acid extension or 'tail'. Bioinformatics programs indicate that this tail lacks a formal structure, and therefore in Figure 2D this part of the protein has been added in red by hand using Adobe Illustrator, below the computer-generated core structure. Often, the researcher uses the computer-generated form as a starting point to simplify the structure into an easily reproducible, symbol-like form.

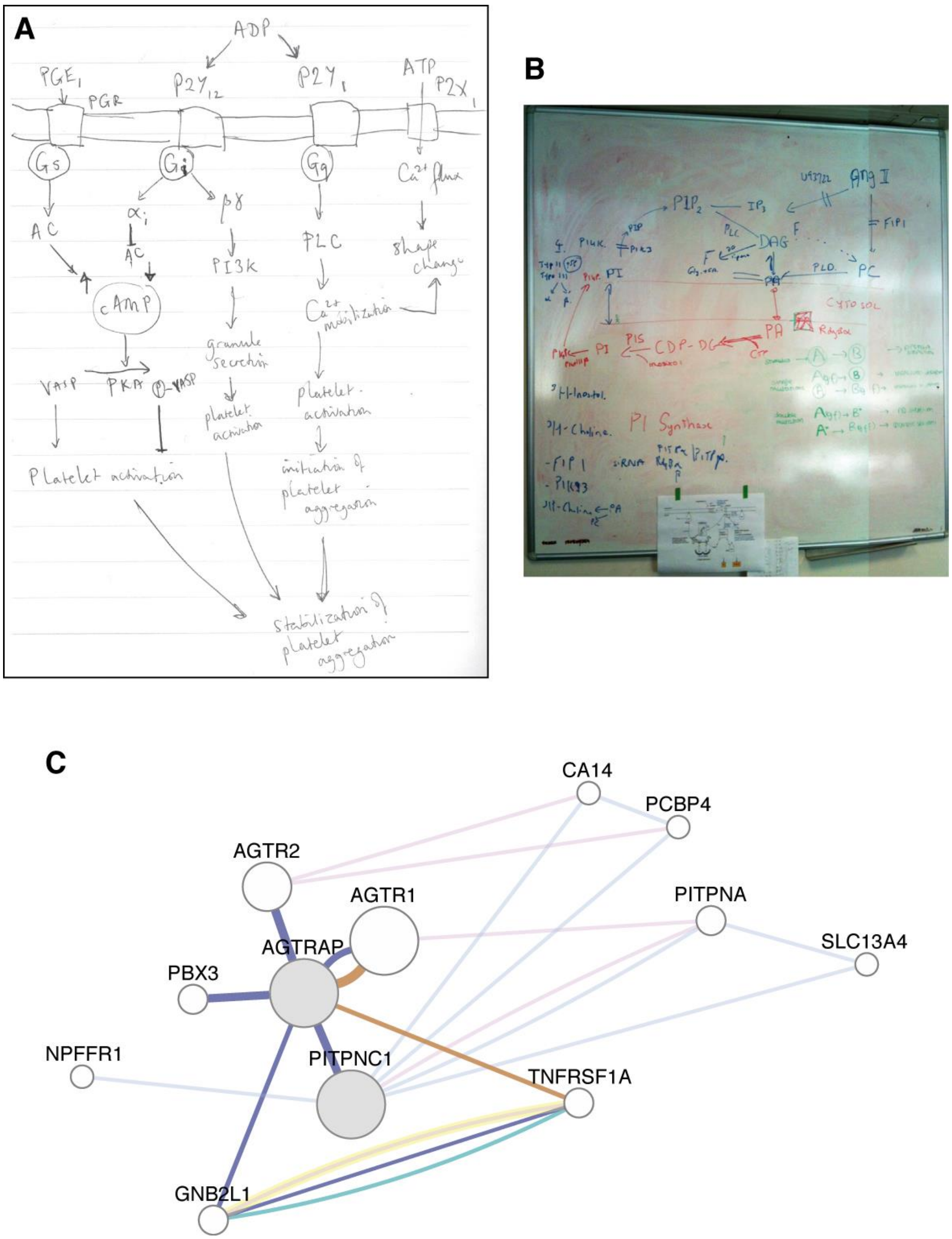

FIGURE 1: PATHWAY DRAWINGS. (A) SKETCH MADE FROM THE SCIENTIFIC LITERATURE OF SIGNALLING PATHWAYS DOWNSTREAM OF BLOOD PLATELET CELL SURFACE RECEPTORS INVOLVED IN PLATELET ACTIVATION AND AGGREGATION FOR BLOOD CLOT FORMATION. BLACK BIRO ON NOTEBOOK PAPER. (B) GENERALISED LIPID SIGNALLING NETWORK WITH COMPOUNDS THAT CAN BE USED TO TARGET PARTICULAR PARTS OF THE PATHWAY. COLOURS USED NOT SIGNIFICANT AND MAY HAVE BEEN CHOSEN MERELY FOR VARIATION. DRY-WIPE MARKER ON WHITEBOARD. NOTE ALSO DIGITAL DRAWING OF A DIFFERENT PART OF THE PATHWAY FIXED TO THE BOTTOM OF THE BOARD. (C) INTERACTIONS INVOLVING AGTRAP (ATRAP) AND PITPNC1 (RDGBB) PROTEINS, GENERATED USING THE GENEMANIA INTERACTIVE SOFTWARE (MOSTAFAVI ET AL. 2008). WEB NODES CAN BE DRAGGED BY THE USER TO CHANGE THE NETWORK SHAPE OR EMPHASIS, AS REQUIRED. PURPLE-BLUE, PHYSICAL INTERACTIONS REPORTED; PINK, PROTEINS HAVE A COMMON PATTERN OF EXPRESSION; ORANGE, INTERACTION PREDICTED BY COMPUTATIONAL METHODS; TURQUOISE, PROTEINS HAVE BEEN REPORTED TO LIE IN THE SAME PATHWAY; PALE BLUE, PROTEINS CO-LOCALISE.

In the next figure, the RdgBβ structure has been simplified so that the core domain is represented by a rough lozenge-shape (Figure 3A), or hexagon containing a phospholipid (Figure 3B). This simplified structure retains its long tail, characteristic of this protein. Using this process, a large dataset (the co-ordinates of atoms in space) is made into a drawing by computer software that produces images in response to a defined set of rules. This has the potential to uncover information about individual proteins, perhaps providing clues about the location and characteristics of potential interaction surfaces. This may then feed forward to imaginative drawings and the design of new experiments, which have the potential to produce further large, unwieldy datasets.

The design of new experiments

Armed with a broad understanding of the scientific literature and bursting with new theories to test, the next stage in the research process is the experimentation itself. Drawing is key here too, although those made are more likely to remain on scraps of paper or hidden in lab books to be viewed only by their maker.

Whereas drawings made whilst understanding what has come before could also be referred to as diagrams, those made whilst thinking about and planning experiments may also be thought of as maps. These may be maps of activity or time over a day, week or month, detailing several experiments at different stages, including preparation and data analysis. They may also be the maps of the experiments themselves: the layout of test-tubes in a rack, or conditions on a cell culture plate (an example of the latter is shown in Figure 4). Drawings of this type ensure the experiment is properly planned with the correct controls before time and resources are spent. They also allow the experiment to be set up in such a way that will minimise errors, reagents and laboratory ware. Lastly, when many experiments have been carried out and the outcome known, maps of figures to be made for publication might be produced, arranged in such a way so as to convey one's findings as clearly as possible.

The results of the new experiments may next be used to modify or confirm predictions made in the early part of the drawing cycle. They may cause rough, transient drawings to be discarded or forgotten. Alternatively, new results might lead to particular drawings and ideas increasing in permanence by digitalization methods or by fixing to a wall. The scientific literature might again be consulted, in light of new results. These new results might themselves be published, further contributing to the greater knowledge. From here, new theories can be conceived, new experiments planned, and so the cycle of drawing in biomolecular research continues.

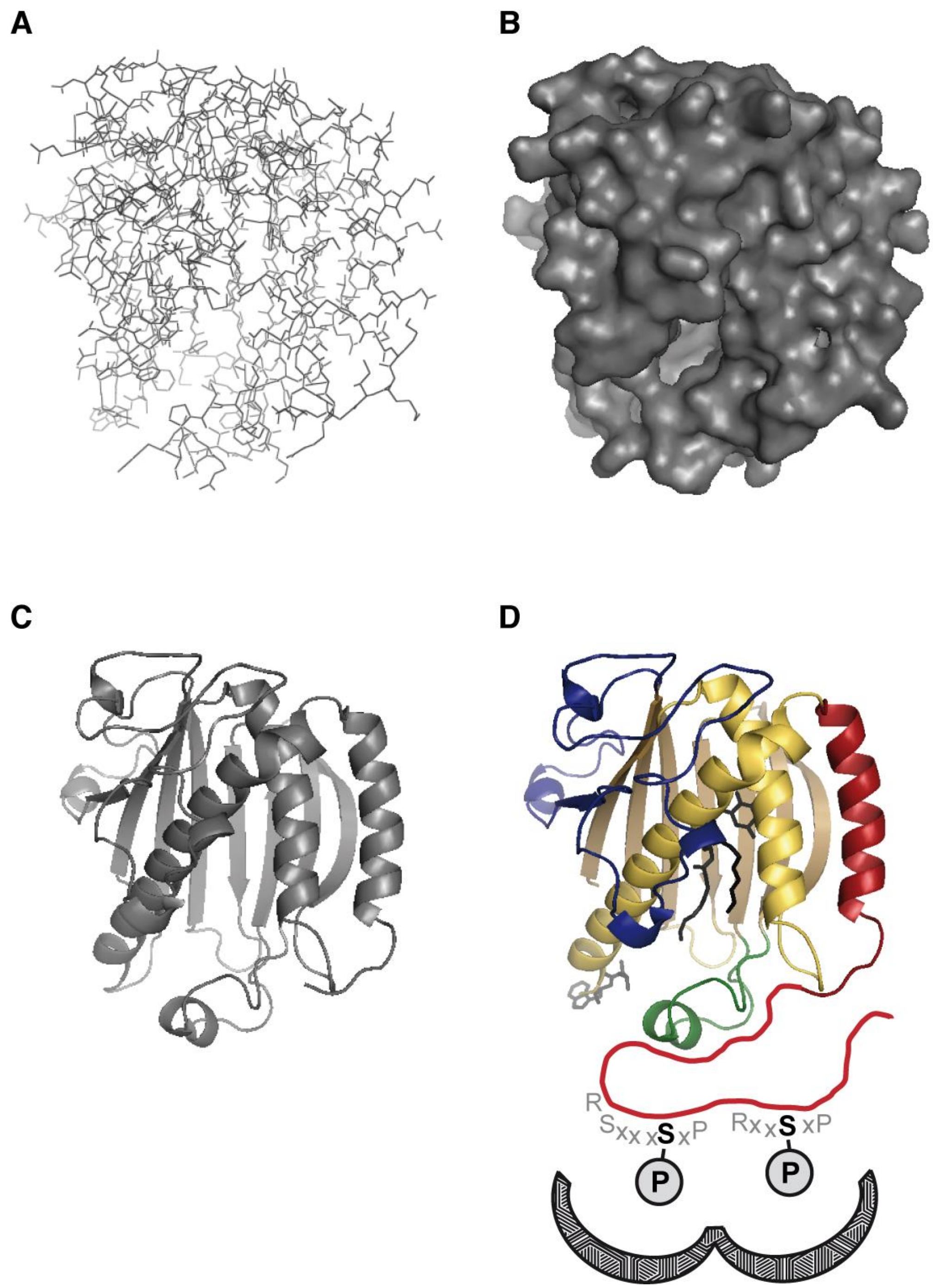

FIGURE 2: DRAWINGS DESCRIBING PROTEIN STRUCTURE. RDGBB STRUCTURE MODELLED ON THE X-RAY CRYSTAL STRUCTURE OF PITPA BINDING PHOSPHATIDYLCHOLINE (PDB: 1T27; (YODER ET AL. 2001)) USING MODELLER SOFTWARE (ESWAR ET AL. 2006). STRUCTURE VISUALISED USING PYMOL MOLECULAR GRAPHICS SYSTEM, VERSION 0.99, SCHRÖDINGER, LLC. (A) BONDS BETWEEN ATOMS IN THE PROTEIN STRUCTURE SHOWN AS LINES. (B) MOLECULE RENDERED TO SHOW WHAT THE SURFACE OF THE PROTEIN LOOKS LIKE. (C) PROTEIN STRUCTURE SHOWN AS A CARTOON WITH A-HELICES AND B-SHEET USED TO SHOW THE DIFFERENT CONNECTIVITY BETWEEN THE PROTEIN RESIDUES. (D) CARTOON STRUCTURE COLOURED TO HIGHLIGHT DIFFERENT PARTS OF THE STRUCTURE: RED, AG-HELIX; BLUE, REGULATORY LOOP; GREEN, LIPID EXCHANGE LOOP. PHOSPHATIDYLINOSITOL LIGAND HAS BEEN SUPERIMPOSED INTO THE BINDING POCKET AND IS COLOURED BLACK. FURTHER ELEMENTS HAVE BEEN ADDED IN ADOBE ILLUSTRATOR: LONG, DISORDERED C-TERMINAL REGION (RED); R, S, P DENOTE AMINO ACIDS FORMING A CONSENSUS SITE FOR 14-3-3 BINDING. LETTER P IN A CIRCLE STANDS FOR A PHOSPHATE MOIETY, WHICH MODIFIES EACH OF THE SERINE (S) RESIDUES IN THE PROTEIN TAIL AND IS REQUIRED FOR 14-3-3 BINDING (GARNER ET AL. 2011). DIMERIC CUP-SHAPED STRUCTURE AT THE BOTTOM OF THE DRAWING SYMBOLISES THE 14-3-3 PROTEIN.

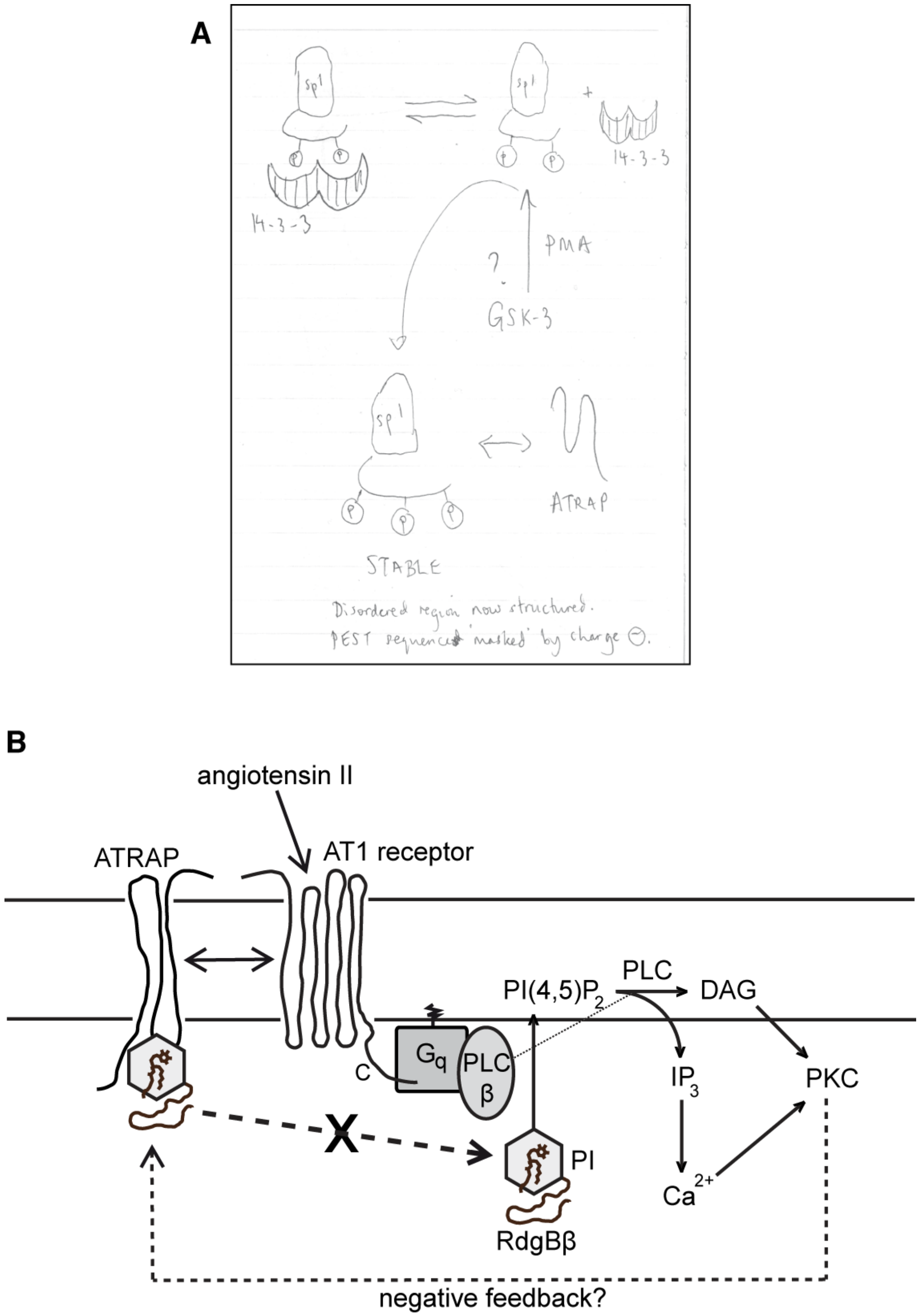

FIGURE 3: SCHEMATIC DRAWINGS MADE IN AN EFFORT TO UNDERSTAND PROTEIN FUNCTION. (A) BLACK BIRO ON NOTEBOOK PAGE. (B) DIGITAL DRAWING MADE USING ADOBE ILLUSTRATOR SOFTWARE. ILLUSTRATION FROM POSTER PRESENTED AT *SIGNALLING 2011: A BIOCHEMICAL SOCIETY CENTENARY CELEBRATION*, UNIVERSITY OF EDINBURGH, UK, 8-10 JUNE 2011, AND *2ND BHF FELLOWS DAY*, QUEENS' COLLEGE, CAMBRIDGE, UK, 4-5 APRIL 2011.

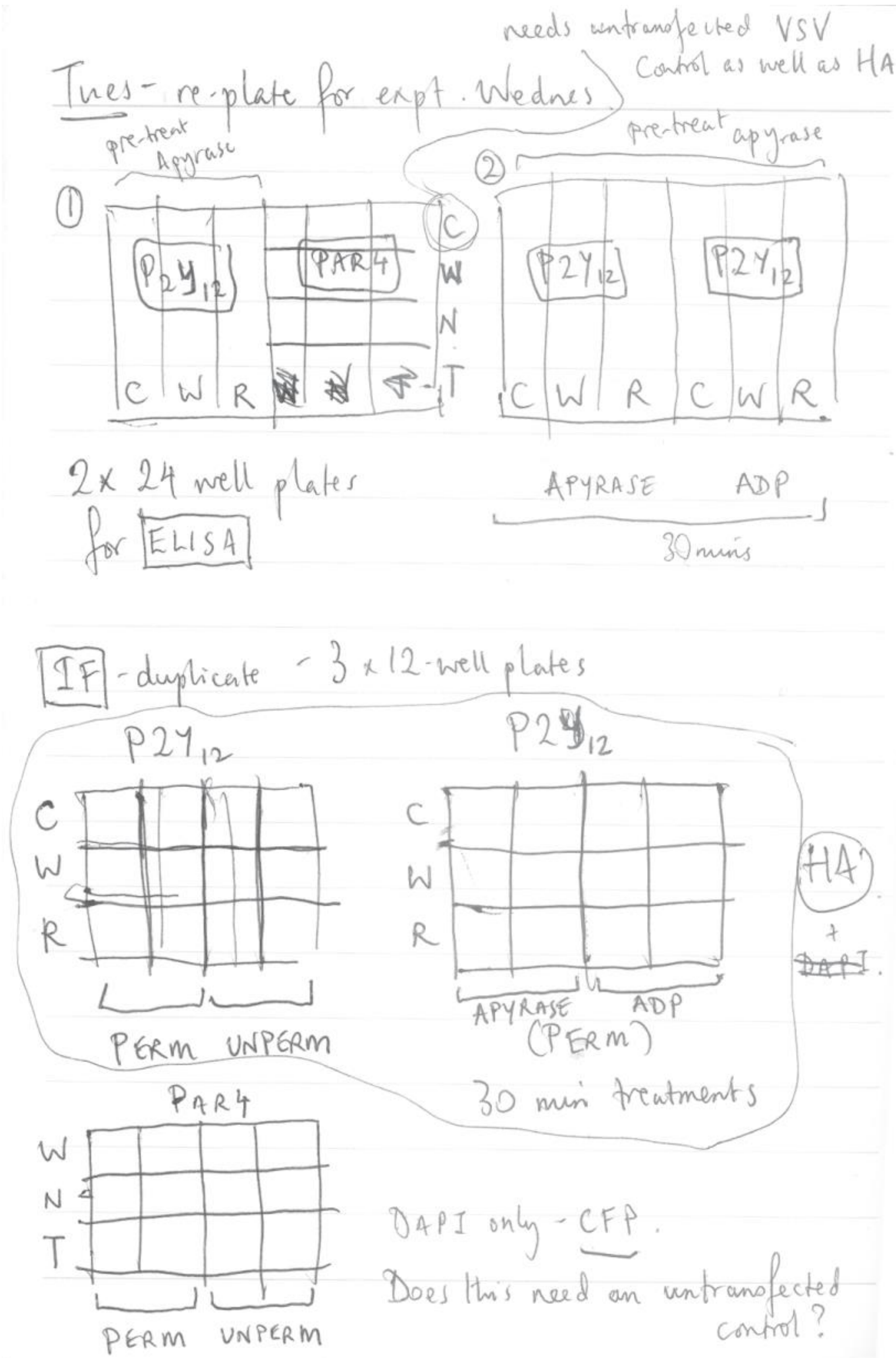

FIGURE 4: DRAWING IN EXPERIMENT PLANNING. RECTANGULAR GRIDS DENOTE 12- OR 24-WELL CELL CULTURE DISHES, AND ASSOCIATED ANNOTATIONS INDICATE POSITION OF PARTICULAR REACTION CONDITIONS IN ENZYME-LINKED IMMUNOSORBENT ASSAY (ELISA) AND IMMUNOFLUORESCENT (IF) MICROSCOPY EXPERIMENTS. BLACK BIRO ON NOTEBOOK PAGE.

CONCLUSION

It is clear that the activity of drawing plays a key role in every stage of the research process, from digesting the wider scientific literature and conceiving new hypotheses, planning time and experiments, to the integration of experimental results within the existing framework of understanding. In this way, a cycle of drawing is undertaken, with the results of new experiments informing the next drawing cycle. Drawings begin as transient objects, being made more permanent should the theories and processes they propose persist.

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Special Edition:
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GEOMETRIC REASONING AND DRAWING: POSSIBLE INTERCONNECTIONS AMONG STEM SUBJECTS AND ART

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Cezanne's famous maxim, "interpret nature in terms of the cylinder, the sphere, the cone," (Loran, 2006: 8) describes a form of artistic envisioning that was of immense value for post-impressionist landscape painting, but that had origins in far earlier traditions in both western and non-western art. The kind of visual thinking Cezanne refers to is also important in the full range of "STEM" subjects—science, technology, engineering, and mathematics—where the ability to imagine and manipulate forms in space plays a fundamental role in problem solving (Cunningham, 2005; Hegarty 2010; Hegarty and Kozhevnikov, 1999). Here we describe a study that explores possible connections between artistic envisioning (Hetland, Winner, Veenema, and Sheridan, 2007) and geometry, an area of mathematics that relies heavily on spatial reasoning. We also consider possible applications of this study to drawing instruction. We set the stage with a short discussion of how visualising and drawing—both fundamental tools of the artist, designer, illustrator, and architect—can also be critical to thinking in STEM disciplines.

We first consider ways that mathematical thinking might influence the visual arts (and vice versa—how the visual arts might influence mathematical and scientific thinking). In terms of the former, the use of geometric shapes, forms, and patterns has a long and rich history in art from many cultures. An obvious example is Cubism, the Modernist movement that was inspired in equal measure by Cezanne's interpretation of nature and the geometrically stylised art of Africa and Oceania. Innovative for its time, Cubism was actually a relatively late manifestation of an artistic, scientific, and philosophical tradition that extends back at least to ancient Greece and the doctrine, in the words of historian of mathematics Morris Kline "that the essence of nature is mathematical law" (Kline, 1957: 623).

Greek architecture, for example, is based on the Golden Section; a similar attention to "ideal" proportions characterised the work of Renaissance artists and architects, where it found expression in such famous images as da Vinci's "Vitruvian Man.' The notion that nature was grounded in mathematical law inspired another well-known Renaissance innovation, linear perspective. Renaissance painters, "imbued with this belief [about the relationship between mathematics and nature]…struggled for over a hundred years to find a mathematical scheme which would enable them to depict the three-dimensional real world on a two-dimensional canvas. . . .It was very fortunate that the painters were also architects and engineers and, in fact, the best mathematicians of the fifteenth century" (Kline, 1957: 623).

What began as a solution to an artistic need became, over time, its own branch of mathematics: two hundred years after perspective was invented, "[p]rofessional mathematicians took over the investigations of these questions and developed a geometry of great generality and power. Its name is projective geometry" (Kline, 1957: 624). The interconnectedness between visual arts and STEM subjects is further illustrated by Kline's observation that Gérard Desargues, a self-taught engineer and architect, "sought to combine the many theorems on perspective [from projective geometry] in[to] compact form that would be useful to artists, engineers and stonecutters. . . .[Desargues' theorem is] still fundamental in the subject of projective geometry" (Kline, 1957: 626).

In the sciences the importance of visual thinking (and of the role of drawing and sketching as a way of representing ideas) is underscored in accounts of mental processes by figures such as Einstein (Hadamard, 1945), Watson and Crick (Watson, 1968), Kekulé (Rocke, 2010), and Tesla (McKim, 1972). In many such cases, ideas that take shape in part through visualisations may then become refined and communicated through sketches and diagrams. For example, the chemist Kekulé, who is famously reported as having identified the ring-like structure of the benzene molecule by interpreting a dream of a snake biting its own tail, recounted a similar instance of envisioning which led him "from valence theory to the much more consequential theory of chemical structure." After having had a vision while riding half-asleep on board an omnibus, he spent part of the night "committing at least sketches of these dream figures to paper. This was the birth of the structure theory" (Rocke, 2011: 63). McKim also notes that drawing played an important role in James Watson's thinking, noting that Watson recollected that an important idea regarding the structure of DNA "came while I was drawing the fused rings of adenine on paper" (McKim, 1972: 9).

For the visual artist and the STEM practitioner alike, drawing, particularly sketching, offers a means of representing structure and relationships, and for holding these still for inspection, reflection, and correction.

> *Drawing not only helps to bring vague inner images into focus. It also provides a record of the advancing thought stream. Further, drawing provides a function that memory cannot: the most brilliant imaginer cannot compare a number of images, side by side in memory, as one can compare a wall of tacked up idea-sketches (McKim, 1972: 10).*

McKim (1972) calls this use of drawing *graphic ideation*, as contrasted to drawing intended to communicate more fully formed ideas to others. While McKim describes drawing as an *aid to* thinking or *a reflection* of thought, however, Kantrowitz (2012) has argued that drawing *is* thinking. Indeed, her position reinforces McKim's suggestion that training in certain approaches to drawing—for example, rapid sketching—is actually training in the kinds of rich, pattern-seeking thought that can yield new and creative ideas. Although McKim suggests that other approaches to drawing such as careful rendering may impede creative thought, we argue here that the close analysis of shape and space required by observational or technical drawing and drafting may pay large dividends in terms of promoting STEM thinking, whether creative, critical, investigative, or reflective. In the remainder of this paper, such questions are considered as we discuss two research studies and an exploratory foray, each investigating possible relationships between training in the visual arts and geometric reasoning.

MIGHT VISUAL ARTS TRAINING IMPROVE GEOMETRIC REASONING? THREE EXPLORATORY STUDIES

The question of whether study of the visual arts might affect mathematical (specifically, geometric) thinking grew out of a meta-analysis of the research on connections between the arts and academic achievement (Winner and Hetland, 2000). Winner and Hetland concluded that there was little empirical evidence to support the frequently advanced claim that "the arts make you smarter" (i.e., that arts training results in improved academic achievement). They also concluded that the lack of evidence did not necessarily mean that there was no relationship, but rather that many of the studies were weak methodologically. Perhaps the most significant deficiency was a lack of articulation of the kinds of knowledge or skills developed in "parent" art domains that might reasonably be expected to transfer to other academic domains. Their subsequent ethnographic study of art instruction in two arts-based high schools was an effort to identify such skills. Hetland and colleagues identified eight "studio habits of mind" that characterised students' training across the five studio classes they studied (Hetland, Winner, Veenema, and Sheriden, 2007, 2013).

One of the eight habits they identified, "envisioning," seemed the most promising for exploring transfer from visual arts to STEM domains. Hetland et al. (2007, 2013) described envisioning as follows.

> *Envisioning includes the acts of generating mental images so that one can imagine how a work will look, and planning ways to achieve that image…When we envision, we imagine and generate images of possibilities in our mind…The translation from model to representation cannot be done without envisioning. Artists aim to represent not only the surface aspects of their models but also the underlying structure or geometry—for example, the axis of the head versus the axis of the body, the torso as a trapezoid, the triangular relation between two figures (Hetland et al., 2007: 48).*

As suggested earlier, virtually every STEM discipline calls on visual or spatial thinking—thinking that likely shares characteristics with artistic envisioning. For example, geometer Walter Whiteley observed:

> *I am a research mathematician, working in discrete applied geometry. My own practice of mathematics is deeply visual: the problems I pose, the methods I use;*

the ways I find solutions; the way I communicate my results. The visual is central to mathematics as I experience it (Whiteley, 2004: 1).

With examples such as these in mind, we have undertaken two studies designed to explore connections between training in the visual arts (in which envisioning constitutes a significant component) and students' ability to reason geometrically. In both cases, we found that visual arts students outperformed non-art student peers on geometric reasoning tasks.

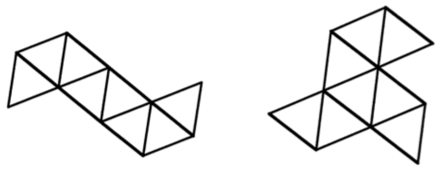
Study 1: Geometric Reasoning in Collegiate Studio Arts Majors and Psychology Majors

In this study we explored the question of whether studio arts majors (who it is assumed were trained to engage in artistic envisioning) would demonstrate stronger geometric reasoning than psychology majors, whose content area major did not rely heavily on envisioning (Walker, Winner, Hetland, Simmons, and Goldsmith, 2011). We collected data from 36 college undergraduates attending Winthrop University in North Carolina (USA): 18 studio art majors and 18 psychology majors. Students in both groups had completed an average of 6.5 semesters of college (they were mid-way through the first half of their final year), and participants in both groups had, on average, taken about the same number of mathematics classes (psychology majors averaged 1.7 years of math in college and 4 years in high school; studio arts majors averaged 1.4 years of math in college and 3.8 years in high school). The arts majors had completed an average of 16 undergraduate art courses; the psychology majors had taken no more than one arts course while enrolled in the college.

We administered a Geometric Workout assessment (Callahan, 1992) and the two verbal intelligence scales of the Kaufman Brief Intelligence Test (KBIT). Groups of students completed the tasks individually during designated testing sessions apart from their regular class meetings. The geometric reasoning test was based on a series of tasks created by mathematician Patrick Callahan for his college-level mathematics classes. The 27-item test required students to rely on visual working memory as they engaged in various spatial transformations. Examples of problems from the test include the following:

Imagine you have two squares of the same size. You place one square on top of the other, rotating the top square 45 degrees. (Remember that 45 degrees is half of 90 degrees.) What shape is the overlapping region? Try to figure out the answer in your head without drawing. Describe your answer in words as best you can. (Answer: an octagon or other 8-sided figure)

Below are pictures of "nets." You can fold them on the solid lines to make 3-dimensional forms. Circle the one that can be folded into a closed form (that is, one that has no holes or openings). (Answer: Net 1)



Net 1 *Net 2*

The verbal tasks included naming pictures and using a clue to complete a word with missing letters (e.g., BR_N: "a dark colour" [brown]; _ _ RE_ _ I _ I _ Y: "due to chance or fate" [serendipity]).

Studio arts students' performance on the geometry test was, on average, significantly higher than that of the psychology group (Figure 1). Regression analysis indicated that, when controlling for the effects of verbal intelligence (as measured by the KBIT), training in the arts was a statistically significant predictor of performance on the Geometric Workouts task (b=.34, $t(34)$,=2.31, p=.027).

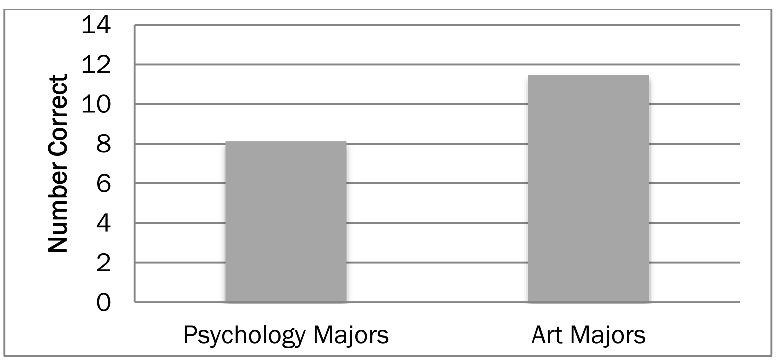


FIGURE 1: GEOMETRY WORKOUT SCORES: GEOMETRY AND STUDIO ARTS MAJORS

Study 2: Exploration of Students in Three Different Drawing Classes

As a follow-up of this study, Simmons and his colleagues conducted a pilot exploration of the effect of college level drawing classes on students' abilities to engage in artistic envisioning. One of the goals of this work was to understand whether art students do, in fact, develop geometric envisioning skills through taking art/design classes, or whether they come to art programs because they already have such innate and/or previously trained capacities. More immediately, the researchers, as faculty members in Fine Arts and Visual Communication Design programs, wanted to see whether such skills were currently being taught in their departments' foundation drawing classes.

Simmons and colleagues collected drawings from 58 first and second year college undergraduates who were enrolled in three different semester-long drawing courses: first semester design drawing (16 Visual Communication Design majors), first semester fine arts drawing (32 Fine Arts and Art Education majors), and Illustration I (10 Illustration majors). Of these three groups, students in the design drawing class were on average the least experienced in drawing, while the students in the illustration class were the most advanced, having already taken foundation design drawing classes. Students in all three groups completed three drawing tasks at the beginning and end of the semester; each task involved envisioning (visualising and mentally manipulating shape and spatial relations). These tasks are briefly described below.

Descriptive geometry drawings (Watts and Rule, 1946). These drawings required the translation of three orthographic views of a cuboid object (plan view, front elevation and side elevation) into a drawing as an isometric projection (Figure 2). The task began with rather simple problems that became increasingly complex; students were to draw as many as they could in the 10 minutes allowed. This kind of exercise can be used to develop designers' capacities to imagine an object as a solid form that they could then imaginatively rotate to view from any angle (Hanks and Belliston, 2008).

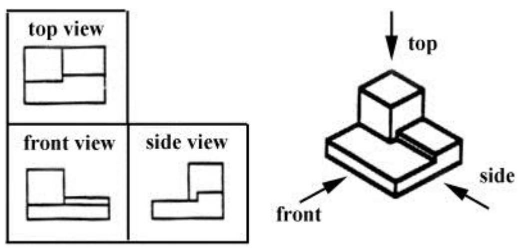


FIGURE 2: ORTHOGRAPHIC DRAWING OF A SIMPLE BUILDING (BLANCO, WILSON, JOHNSON, AND FLEMINGS, N.D.)

Drawing objects in perspective. This task involved using an orthographic drawing of a set of simple objects, shown in plan and front and side elevations, to draw the arrangement of objects in perspective as might be seen from a given viewpoint (indicated by an arrow). Successful drawings represented the envisioned objects with proper positions and proportions as well as with accurate overlaps as one form would have appeared when seen behind another (Figure 3).

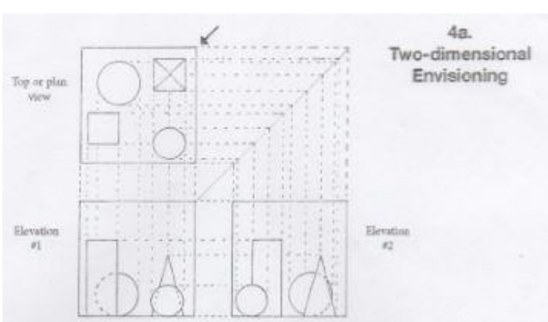


FIGURE 3: DRAWING OBJECTS IN PERSPECTIVE FROM A PLAN DRAWING (COURTESY OF D. G. BROWN)

Drawing a plan view from a perspective view. This task was essentially the opposite exercise; students started with a perspective drawing of the same objects and were to delineate the arrangement in a plan view (Figure 4).

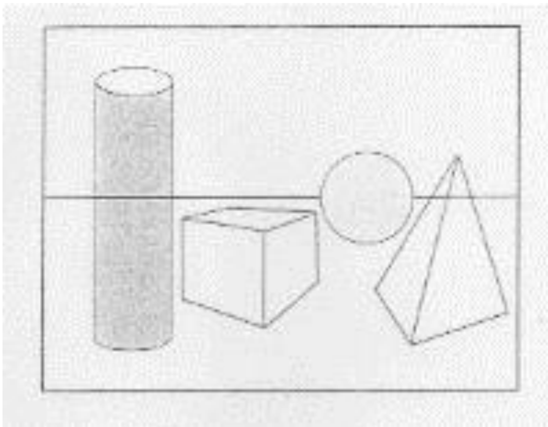


FIGURE 4: DRAWING A PLAN VIEW FROM A PERSPECTIVE DRAWING (COURTESY OF D. G. BROWN)

We did not conduct statistical comparisons of the drawings in the three groups, but holistic comparisons of the pre- and post-course drawings suggested that, students in fine arts and design drawing classes showed little to no change in their abilities to perform these three types of drawing tasks; students in the illustration class did evidence some global improvement on all three. Some of the students, especially those in the fine arts class, failed to see a connection between these tasks and their ideas about what constituted drawing. A number of students voiced resentment at having to complete the envisioning tasks, particularly the descriptive geometry problems, and some found the task virtually impossible to understand even after several demonstrations by their teachers. We wondered whether their resistance, sometimes expressed rather vehemently, simply reflected students' lack of experience doing such tasks or perhaps a deep-seated prejudice against having to use logic and mathematical skills in the service of art. We will return to these questions and to other implications of this exploration with drawing classes in our conclusion.

Study 3: Longitudinal Study of Geometric Reasoning in High School Students

The third study, still in the data analysis phase, is a Boston-based, quasi-experimental longitudinal investigation of the same general question: Does study of visual arts help students develop envisioning skills that support geometric reasoning? We are comparing three groups of 9th graders on measures of spatial geometric reasoning and artistic envisioning as well as on standard measures of spatial skill: visual arts students (VA), theater students (T) and students taking intensive squash lessons (SB).

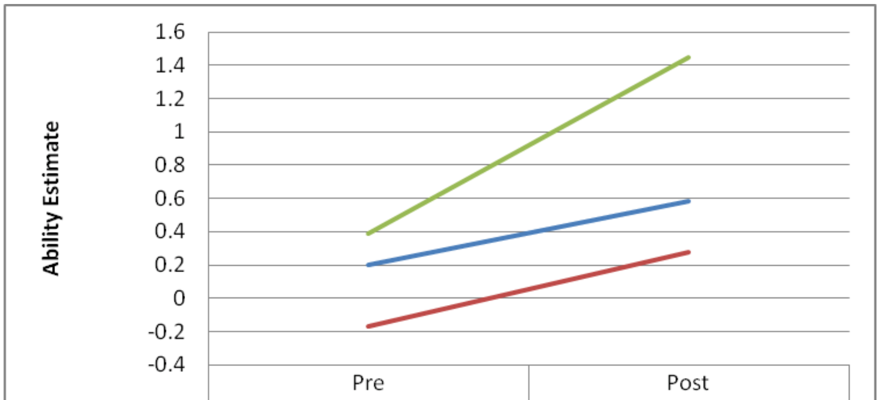
The visual arts participants (VA) attended an arts-based public high school, where they spent the mornings studying core academic subjects and the afternoon studying visual arts. The 9th grade visual arts curriculum includes a year-long drawing class. A small number of VA students were recruited from Artists for Humanity (AFH), an after-school, apprentice-style entrepreneurial arts program which students attend for nine hours each week. The theater students (T) attended the same arts-based high school and followed the same schedule as the VA students, studying drama and stagecraft in the afternoons. Students in the sports condition (SB) participate in an intensive, nine-hour per week after-school squash program. Virtually all students were from low SES urban populations and attended schools in the Boston public system.

We tested students at three time-points: beginning of 9th grade (pretest), end of 9th grade (posttest 1), and end of 10th grade (posttest 2). At each testing point, students completed the measures over two sessions approximately one week apart. Each session lasted approximately 70 minutes. The measures we used are as follows.

1. *The Geometry Reasoning Test was composed primarily of release items from NAEP, TIMSS, and PISA. Items were selected that tested reasoning rather than technical vocabulary or skill with formal proofs. The test has two equivalent forms administered in counterbalanced order at pretest, posttest1 and posttest2.*
2. *The Art Envisioning Test was developed for this project. It assesses aspects of artistic envisioning that have spatial qualities:*
   - *translating between 3-D and 2-D (drawing a 3-D scene from life; re-creating a pictured scene with 3-D figures)*
   - *abstraction (rendering a complex figure in terms of underlying simplified forms)*
   - *projection (drawing and/or identifying shape, size, and direction of cast shadows given an imagined light source)*
   - *mental rotation (drawing a scene from life from a 180 degree change of perspective)*
3. *Spatial Factors tests that assess the three major "pure" spatial factors (Linn and Petersen, 1985)*
   - *spatial perception (water levels task, Liben, 1991)*
   - *mental rotation (Vandenberg and Kuse mental rotations; Peters et al., 1995)*
   - *spatial visualisation (paper folding; Ekstrom, French, Harman, with Derman, 1976).*
4. *Control tests that assess abilities for which we hypothesised no differences among the three groups*
   - *CogAt measures of verbal abilities (Lohman, 2002)*
   - *Empathy (Joliffe and Farrington, 2006)*

We hypothesised that the VA students would outperform the T and SB students on all but the control measures of artistic envisioning (i.e., the Geometric Reasoning, Art Envisioning, and Spatial Factors tasks).

Due to the limited class sizes at the arts school, we collected data in three waves over a three year period. Data analysis has been completed to date for the first two waves of data—a sample of 108 cases (41 VA, 35 T, and 32 SB students). Results to date indicate that students in the VA group had statistically higher mean scores on both pre- and post test 1 geometry than did the other two (control) groups ($p < .05$; see Figure 2).



	Pre	Post
SB (n=32)	0.199	0.585
T (n=35)	-0.167	0.275
VA (n=41)	0.386	1.45

FIGURE 2: PRE AND POST-TEST SCORES ON GEOMETRIC REASONING TEST: VISUAL ARTS (VA), THEATER (T), AND SQUASH (SB) STUDENTS

Controlling for pretest differences, membership in the VA group remained a significant predictor of post-test1 geometry scores ($p < .05$; see Figure 2). Additionally, scores on the artistic envisioning pretest were a significant predictor of posttest 1 geometry scores ($p < .05$). At baseline, the data analysed to date indicate that the VA group also outperformed the other two groups on the standardised tests of spatial reasoning, but not on the two control tasks, as we had hypothesised.

Despite these findings suggesting that levels of visual arts thinking are linked to levels of geometric reasoning, we were not able to demonstrate that visual arts training, when compared to the theater and sports training, fostered greater *improvement* on the artistic envisioning test. Thus our hypothesis that more art instruction would cause higher levels of artistic envisioning and predict gains in geometric reasoning has not been borne out. Further work would be needed to determine whether the lack of selective improvement by the arts group on the art envisioning test reflects limitations in the "construct validity" of the art envisioning test; that is, that our art envision test did not assess the kind of envisioning that led to the art group improving more than the control group on geometric reasoning.

The analysis of two of our three waves of data indicates that VA students performed better than the other groups on the tasks tapping visualisation skills. However, given that the students self-selected into visual arts, theater, and sports, we cannot determine whether the observed difference is a result of spatially skilled students self-selecting into the visual arts, or whether study of the visual arts promotes the development of envisioning skills that are applicable to other domains of study, or both. A definitive answer requires conducting an intervention study which randomly assigns students to drawing and non-drawing "treatments."

In the next section, we conclude with some implications for drawing research and drawing instruction, considering how we might intentionally strengthen art students' capacities for geometric reasoning and related envisioning abilities. For even if it turns out that art students come innately equipped with capacities to reason geometrically, these capacities warrant intentional cultivation if they are to become active aspects of their creative problem-solving tool kit, especially if such problem-solving is eventually to be applied across disciplines in later studies and work.

IMPLICATIONS: ENVISIONING THROUGH DRAWING, IN ART AND ACROSS DISCIPLINES

The way in which we distinguish among disciplines and divide up the curriculum positions our educational system poorly for taking advantage of the potential for cross-discipline synergies such as those we explored in our studies of artistic envisioning. Yet the separation of "academic" and "artistic" disciplines has not always been the case. Art academies commonly included rigorous education in mathematics. From their beginnings in the 15th century under the inspiration of multi-disciplinary figures such as Leonardo da Vinci (McMahon, 1956) to their demise in the mid-twentieth century under the attack of Modernism, art academies commonly included rigorous education in mathematics (Pevsner, 1973). Moreover, even for those outside the arts, drawing courses involving explicit mathematical components were, until relatively recently, rather commonplace in public education throughout Europe and the United States (Efland, 1990; Stankiewicz, 2001).

The potential dividends of a more inclusive education can be considerable. Consider the histories of scientific innovators such as Kekulé, who attributed his capacity to visualise in chemistry to his early training in architecture (Rocke, 2010), and Nobel laureate physicist Luis Alvarez, who attended an "arts and craft" high school where the curriculum included industrial drawing and woodworking. Alvarez credited these experiences as contributing to his ability to both visualise the phenomena he studied professionally and also to design and build his own experimental equipment (Alvarez, 1987; Root-Bernstein and Root-Bernstein, 2013). Innovator and entrepreneur Steve Jobs also credited the arts, in particular a calligraphy course in college, as an important factor in his accomplishments at Apple (Isaccson, 2011).

Clearly, the needs of the future must be met by people who can cross boundaries and synthesise knowledge from disparate domains (Gardner, 2008), bringing diverse ways of problem posing and problem solving to bear on the pressing concerns we face today and on the unforeseeable challenges we will face in years to come. The process of developing such boundary-crossing minds in larger number may begin with conversations across professional cultures like those happening at conferences on drawing and cognition. Next steps must involve more concerted efforts at both research and educational interventions. In regard to the former, the projects addressed in this paper, and other studies recounted in this volume, should provoke more expansive and extensive research into cognition in and through drawing.

Other projects might include a survey of college-level foundation drawing classes and high school art classes to determine how drawing is currently taught and to gather information about the percentage of class time devoted to drawing that trains the kinds of artistic envisioning/reasoning that we have suggested might be transferrable to STEM domains. A related question is: to what degree do design schools still teach traditional skills like descriptive geometry and linear perspective vs. relying on digital design programs like *Revit*?

This kind of survey approach could lead to inquiry into the benefits of drawing by hand vs. using digital media, whether in design, illustration, or in fine arts. Concerns about such issues, and the larger question of what capacities (perceptual and conceptual) might be lost if designers and architects stopped drawing altogether, prompted a conference at the Yale School of Architecture in 2012 entitled *Is Drawing Dead?* (Yale, 2012). The answer was "not yet," with many participants insisting that hand drawing is still essential for ideation despite admitting the value of digital media for technical drawing and rendering.

Another line of work would involve developing greater understanding of existing connections between STEM studies and drawing as a way of providing models and design principles for future programs. With funding from the National Art Education Foundation, Andrea Kantrowitz and Seymour Simmons are gathering exemplars of K–12 teachers' uses of drawing to connect art with academic disciplines including, but not limited to, STEM studies. Should such research bear fruit, further steps may involve developing and implementing teacher-training programs that will prepare art educators, classroom teachers, and non-art specialists to teach drawing and integrate it throughout the curriculum.

Programs like these would, however, likely challenge several of contemporary education's self-imposed segregations—not only the general boundaries between art and academics, but also those within visual arts education itself, such as the ever-growing divide between fine arts and illustration, and between fine arts and design. Divisions occur even within and among drawing programs themselves, including conflicts between those who promote academic drawing and those who favour more contemporary approaches, between those who emphasise drawing from observation and those who prefer drawing from imagination, or who focus solely on conceptual or abstract drawing.

While valuing each of these approaches and celebrating the differences among them, it is equally useful to identify fundamental continuities uniting them all, continuities with implications for learning and creativity within the wide spectrum of visual arts and across the disciplines. Additional factors that might be considered in a more inclusive view of drawing instruction include the following:

1. *Drawing study may support deeper development of artistic (and STEM) envisioning if it addresses a range of problem-solving challenges and incorporates a range of problem-solving strategies such as the use of descriptive geometry and other visualising practices.*
2. *Drawing instructors could make explicit the connections across disciplines, both in terms of input and output. This kind of "teaching for transfer" is what Perkins and Salomon (1988) call "the high road to transfer" (Perkins and Salomon: 25-28). In terms of input, for lessons that "draw upon" knowledge from other domains like natural science, logic, or mathematics, cross-disciplinary connections would need to be brought directly to students' attention, encouraging them for example to recall what they learned in drawing class and use the knowledge and skills, as appropriate, in geometry class. In short, where drawing skills learned in the context of art have potential applications across disciplinary boundaries, these should be made evident through examples, as well as suggestions about possible future applications.*
3. *An implication of the search for productive "conversations" between the arts and STEM work is to consider creating classes that are co-taught by teams of professionals from art and non-art disciplines in which common principles and strategies are discussed and explored. These collaborations may also create productive environments for generating and testing theories to advance cross-disciplinary thinking, visualising, and problem solving through drawing.*

We are admittedly not the first to make suggestions like those above, and many of our readers may already be involved in such enterprises. An example of what we call for can be seen, for example, in Josef Albers' innovative, comprehensive drawing courses at the Bauhaus, Black Mountain College, and Yale University, which incorporated a range of non-representational and representational drawing skills applicable equally to design and fine arts (Horowitz and Danilowitz, 2006). Another example can be seen in the comprehensive drawing program at Pratt Institute in New York requiring all first-year students to study six distinct but interrelated drawing strategies, including gestural drawing, mark making, and geometric construction (Fasolino, Wirls, and Sloan, 2008). Pratt recently demonstrated its commitment to building cross-disciplinary connections by establishing an endowed chair for mathematics and the arts (Pratt, 2012).

At the K–12 level, several examples of drawing as a cross-curricular vehicle for learning and creating can be found in Ron Berger's 2003 volume, *An ethic of excellence: Building a culture of craftsmanship with students.* Grounded in Berger's background as a carpenter and his expertise in "Expeditionary Learning," his 6th grade curriculum emphasised experiential engagement, individual initiative, team-work, craftsmanship, and cross-curricular problem-solving. The Reggio Emilia schools demonstrate that even very young children can benefit from integrating drawing with "academic" subjects, where drawing is one of their most important "languages of learning" (Edwards, Gandini, and Forman, 1998; Giudici, Rinaldi, and Krechevsky, 2001).

The research described in this essay, taken together with similar topics addressed throughout this edition of TRACY, suggests the potential for a paradigm shift to a more central role in education given to drawing, in its myriad forms, as a means of visualising, representing, and communicating complex ideas. With greater recognition of the importance of "graphicacy" (thinking in images) as a complement to numeracy and literacy at the core of the curriculum (Garner, 2010), it may be possible to help the broader culture re-envision a central role for the arts in education—as a means of connecting, rather than separating, domains of skill and knowledge, and of understanding learning as both "hands on" and "minds on" problem-solving. It is up to those who study drawing, teach drawing, and prepare future drawing teachers to help insure that these potentials are actually realised.

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Special Edition:
Drawing in STEAM

USING SKETCHING: TO THINK, TO RECOGNISE, TO LEARN

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I would like to talk about how it is possible to think with our body and other things. I choose this topic in a workshop on drawing because sketching can, at times, be a way of interactively thinking with pencil and paper – of thinking with things. This process is not unique to drawing, and is, in fact, representative of interactive cognition more generally. The first thing I discuss, then, is this key interactive strategy: the process of creating, projecting and creating structure. I show why projection – which is a process of adding extra features or structure to an external thing that anchors and supports it – can be more powerful than imagination alone.

The second thing I discuss is how the principles underpinning certain types of drawing, in particular, the principles of lithic illustration (Addington 1986) can help paleo-anthropologists decide whether knife-shaped stones are human made or nature made. The act of drawing, when done right, can help anthropologists distinguish a 'knapped' chip mark from an eroded one. Because drawing, albeit in this technical way, partially *simulates* the very process of knapping and chipping stone, it provides paleontologists with a physical way of seeing the way the stone was made. In this case, the act of drawing serves to manage attention so as to produce professional vision.

The third thing I present comes from the dance world: how dancers sketch and 'mark' phrases. When working quickly to learn a dance phrase, dancers will often say they first 'sketch' the movement. This sort of sketching uses the whole body as instrument and of course is ephemeral; it leaves no trace. Later, when practicing, after initially mastering the phrase, they use a related process called marking. When marking, a dancer creates a simplified model of the full movement. It is like a physical sketch but the dancer now knows the phrase much better and uses this simplified version to practice specific aspects. This simpler movement requires less energy, it is less emotional, and it is typically smaller. Marking is a way dancers think with their bodies. They use their bodies as both tool and clay, as instrument and medium.

1. Projection

Prove this claim:

> *All 3 medians of a triangle always intersect at a single point.*[1]

How would you proceed? Most people will reach for a pencil and ruler to solve this kind of question. Why? Because it is too hard to do all the thinking and imaging entirely in their head.

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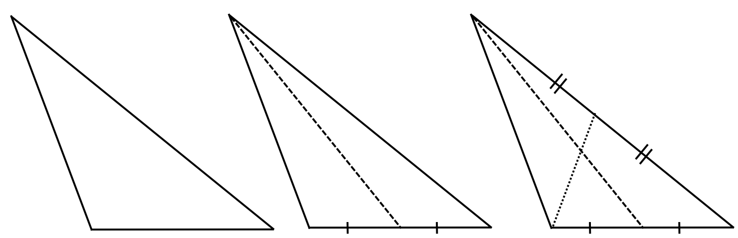
[1] A median is the line from a vertex to the midpoint on its opposite side.

This reveals a key interactive strategy: when you have a problem, if you can solve it in your head, you go ahead and do so. If you can't, though, you typically do something on paper (or with objects nearby, or with tools, models and so on) to help scaffold or enact your thinking.

Look at figure 1. Returning to the median problem, the first thing you probably will do is to create a triangle, as in 1a. The next step is to concentrate on the median. Perhaps you will make one of those mentally rather than drawing it. This mental projection is shown in 1b; because it is projected it is shown here as a dotted line. The other two medians have yet to be constructed. Looking at figure 1b are you able to project both these medians on top of your first projection? This is the test you need to do to probe your intuitions about whether three medians intersect in one point.



1a. 1b. 1c.

FIGURE 1. 1A SHOWS A DRAWN TRIANGLE. IN 1B THE DOTTED LINE REPRESENTS A PROJECTED MEDIAN. IN 1C THE SECOND MEDIAN IS MENTALLY PROJECTED TOO.

If you actually try to do three projections some of you will succeed, but most will not. For me personally, I can project a total of two lines, as in figure 1c, but I can't do a third. I am not confident that I can keep in mind precisely where the other lines intersected, at least precisely enough to be sure my third projection runs exactly through the same point. So I reach for a ruler, and begin to draw all three medians. Once I have two in place I may or may not need to draw the third, depending on how accurate I think my projection of the third median is.

This interactive process of creating structure in the world – that is, drawing a median – then projecting onto it – that is, imagining a median drawn onto the current drawing – then creating more structure, then projecting onto it ... this strategy is how we work much of the time: we do what we can in our heads and when we can't do more we create structure outside to enable us to continue projecting. It is a fundamental interactive strategy.

Project → Create → Project structure

As is clear from our simple geometric example projection gets more faulty the further out you go. It becomes harder and harder to keep all that stuff reliably in your mind. By externalising, we convert mental projection, mental stuff, into a form that is more useful because now it is outside. This cycle of thinking by projecting onto the world, then creating external structure, and projecting some more, lets us go beyond what we can do in our heads alone. By creating things that are stable and persistent outside we are able to compensate for the limits of our imagination.

Although projection is similar to pure imagination it is also different in important ways. In imagination a triangle, for instance, has no specific size. Is it one inch or one meter? Does it even make sense to ask? But when you project a line or a triangle, there is some external structure that supports or anchors the projection. This means that the structure or process you project must have a specific size, and it must be assigned a specific location outside, else it won't anchor correctly to the thing you are looking at. In this respect, projection is like drawing. When you draw a median, as in figure 1b, the line you make is very specific to the triangle it sits in. When you project a median onto that triangle, you are similarly constrained. Your projection has to fit the triangle; it is spatially anchored on that external physical thing.

To test if people were better at projecting than at imagining we performed a simple experiment based on tic-tac-toe. We wanted to see if they would do better when they projected structure onto something rather than imagining the whole thing.

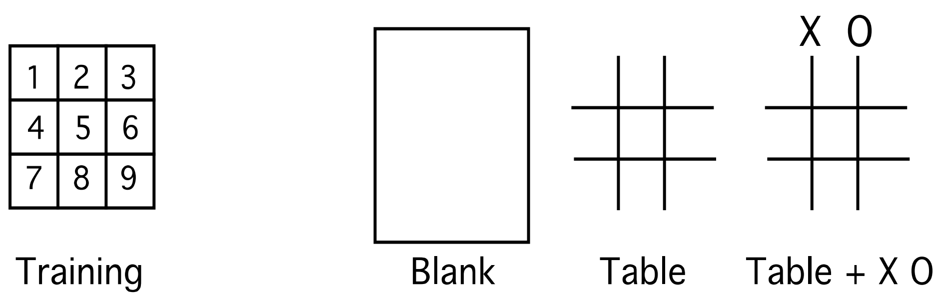


FIGURE 2. WE TRAINED SUBJECTS TO PLAY TIC-TAC-TOE BY CALLING OUT THEIR MOVES USING THE CELL NUMBERS AS SHOWN ON THE LEFT. OPPONENTS ALSO CALLED OUT THEIR MOVES. ON THE RIGHT ARE THE THREE CONDITIONS OF THE EXPERIMENT: BLANK PAGE FOR THE PURE IMAGINATION CONDITION, TABLE FOR THE PROJECTION CONDITION, AND TABLE WITH X AND O FOR A VARIANT OF THE PROJECTION CONDITION.

We trained subjects to play tic-tac-toe by calling out numbers. If a subject wanted to put an X in cell 9, they would call out 9; the experimenter would reply by calling out a number corresponding to the cell (s)he wanted to place her O onto, and so on. The cell grid and the stimuli we used are shown in figure 2. There were three conditions; in the imagination condition, subjects were given a blank piece of paper. Some subjects preferred to close their eyes. In the projection condition, they were given a piece of paper with the standard tic-tac-toe table, or grid, on it. Obviously, they were not allowed to mark the table they had in their hands. In the third condition, they had the same table, but now there was an X and an O above it.

What we found surprised us. We expected people to do better with the table (grid); we predicted that projection would be better than imagination because we thought that having a table would make it easier to form a mental image of the current state of the tic-tac-toe game than having to imagine the whole board. We thought the grid would scaffold projection, making projection a simpler, less demanding task than imagination. But, in fact, subjects, overall, did not benefit from having a grid. The grid did not facilitate memory or imagery, since people did not play better in the grid condition. See figure 3 for the results showing that 'all subjects' (n=21) perform about the same in all conditions.

As part of the study, however, we had our subjects complete a pretest to determine how effective they were at visualising. This pretest consisted of questions requiring subjects to describe how well they visualise, or image in their mind's eye, specific visual situations.[2] For instance, a situation to visualise might be a scene at the beach where a middle-aged man has just inserted a large umbrella into the sand and it is casting a pleasant shadow over his two children, each of whom is sitting on a towel.

Once we divided our population into strong and weak visualisers based on the information from this test the data became far more interesting. We found that strong visualisers perform better overall but they gain nothing of significance when using the table (the normal projection condition). Weak visualisers performed less quickly overall; they derived a tiny bit of improvement from the table, but, as with the strong visualisers, none of these differences were large or statistically significant.

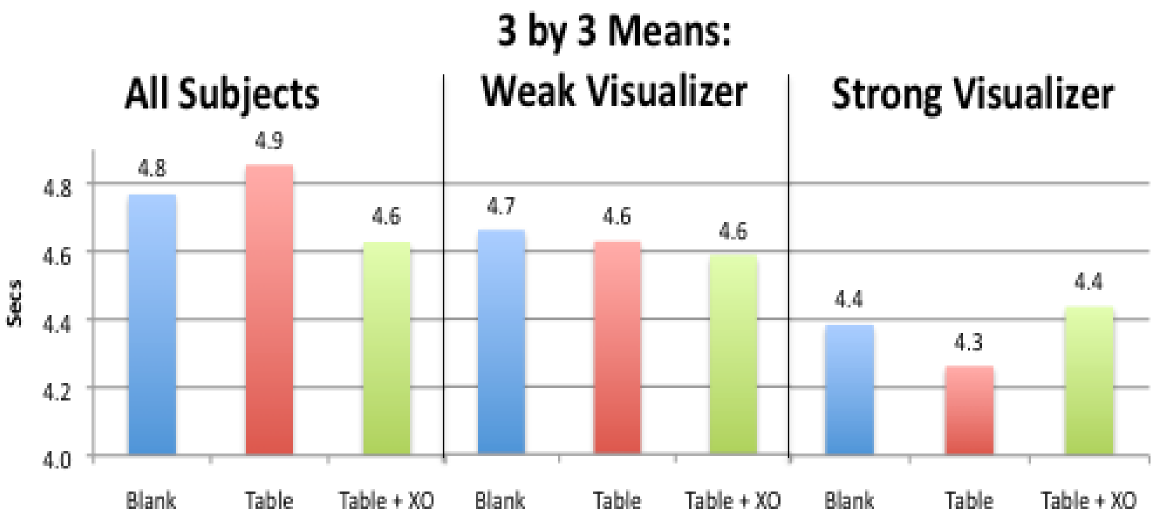


FIGURE 3. OVERALL SUBJECTS DID NOT BENEFIT FROM LOOKING AT AN EMPTY TIC-TAC-TOE TABLE. THE BEST VISUALISERS WERE BETTER THAN THE WEAKEST ONES, AND BOTH STRONG AND WEAK BENEFITED A LITTLE FROM THE GRID, BUT NOTHING WAS SIGNIFICANT

[2] The name of the test is the vividness of visual imagery questionnaire2 (VVIQ2).

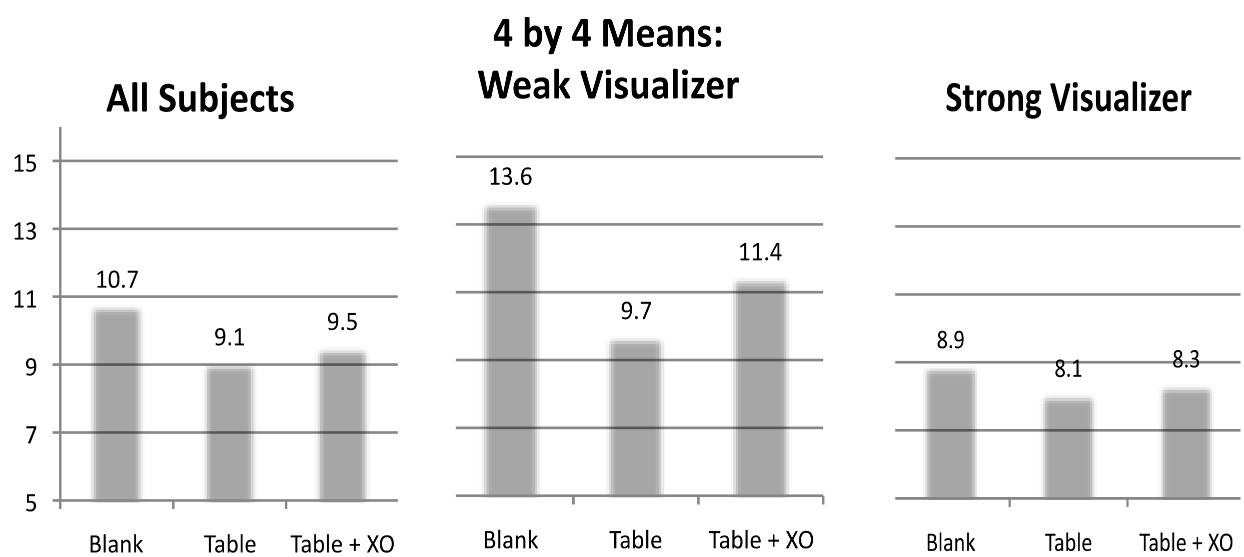


FIGURE 4. IN THE 4 BY 4 GAMES SUBJECTS DID PERFORM SIGNIFICANTLY BETTER WITH A TIC-TAC-TOE TABLE. BUT THOUGH STRONG VISUALISERS BENEFITED ALSO FROM THE TABLE THEY DID NOT YET REACH STATISTICAL SIGNIFICANCE. WEAK VISUALISERS HOWEVER DID SIGNIFICANTLY BETTER IN THE TABLE CONDITION.

We next ran the same stimuli for a larger version of tic-tac-toe, a 4 by 4 table, where the goal is to achieve four in a row to win. Here the results were more as we expected. As shown in figure 4, all subjects perform better when they have a tic-tac-toe board to look at the table or grid condition. Weak visualisers perform significantly slower in every condition than strong visualisers but they benefit much more from the scaffold provided in the table condition. The third condition, a table with an X and O above it, also improves performance, but now it is clear that the X and O symbols diminish the usefulness of the table; they are slight distractors. Strong visualisers, too, benefit from the table, more than in the 3 by 3 game but their improvement here is still not yet significant; it only trends toward significance. Evidently, the task has to be difficult enough that it cannot reliably be done in the head. Whether a 3 by 3, 4 by 4 or even 5 by 5 game can be done in the head is relative to a subject's abilities. Hence, it was predictable that weak visualisers would get more from the scaffolding a table provides. We would also predict that in a 5 by 5 game, where the game is challenging even for strong visualisers, the table condition will finally dominate significantly for all players, weak and strong alike.

Despite the apparent cognitive value of a table many of our subjects reported that it was unhelpful, even getting in the way of mental play. Evidently, there are times when imagination is better than projection. There must be a cost to mental action of placing an image or symbol somewhere in the visual field. This cost appears as important when the mental task is not too challenging. At such moments the cost of anchoring a mental image outweighs the benefits. But as the task increases in difficulty imagination becomes unreliable and the benefits of external structure can be appreciated.

2. Lithic illustration

The second phenomenon I will consider has to do with the power that drawing exerts over perception: it helps direct the eye to what is most relevant. In Paleoanthropology the received method to determine whether a given paleolithic stone is a cutting tool or just an eroded stone that resembles a cutting tool, is to sketch the stone. The 'how to' of sketching lithic stones has been codified in a set of principles of 'lithic illustration' (Addington 1986). Good archaeological illustrators use these principles. But so do practicing Paleoanthropologists. With pencil in hand a person can feel the physical 'problematic' the tool cutter faced. If the problematic of tool making does not feel real the stone was the product of natural erosion. In a sense the need to draw the tool according to lithic principles serves as a proof that the stone is human made. These principles reveal the "scale; the pattern, sequence, direction, and force of blows to the stone; the bulb and platform of percussion; areas of retouch, snapping, and truncation; areas of grinding, battering, or abrasion; fractures caused by heating; the effects of materials; and pitting and sickle sheen." (Lopez 2009) Features of the stone that might be confusing such as embedded fossils, variegated colouration, patina, seams, banding, and crystallisation are left out of the drawing.

The implication is that expert illustrators, when practicing their craft, are forced to scrutinise stones in a special way. They coordinate hand and eye to interactively probe the stone to reveal knapping related features. The need to draw certain lines drives perceptual inquiry. Attention must be managed, and arguably, without the need to sketch, without the presence of the emerging sketch – an external structure that the illustrator is creating – attention would not be managed adequately. Of course, this is an exaggeration. Illustrators have professional vision (Goodwin 1994) and so can see elements of what they would draw without actually drawing. But in drawing, the process of making lines and ensuring they are spaced revealingly, is itself a process that simulates knapping. Using a pencil to draw a curve is physically related to using a knapping stone to flake a chip off a stone. It physically simulates knapping. So, the drawing process can help the illustrator walk through the history of the axehead's making. The drawing is an external representation, and the process of making this representation is a powerful method for structuring attention. It helps the illustrator to figure out what an artifact is by studying 'the details of its making' (ibid).

3. Marking

The third phenomenon to consider here is a form of practice in dance called 'marking'. It bears on the embodied nature of drawing because first, it is often thought of as a type of sketching itself, albeit with a body. In a sense marking is sketching in three dimensions and motion. Second, and more importantly, marking ties in with our theme of projection and creation and our theme of ‘sketching’ as a tool for managing attention and working out ideas.

What is marking? The derivation of the term comes from the phrase ‘marking in time’, a process where dancers run through the steps and transitions of a phrase, preserving duration but compromising on form. Professional dancers begin each day with a few hours of warm up exercise and then are expected to work for another five hours. No one can be expected to practise with full energy and full intensity the entire seven hours. Injuries might occur. Accordingly, when practising, dancers often work on smaller, less energetic versions of their phrases. This marked form looks like a simplified and imperfect model of the real phrase.

To an outside observer watching a dancer execute this simplified form, the look on their face makes it seem as if the dancer simultaneously has in mind the more complex, more energetic phrase they are marking. They seem to be doing one thing in the world and another in their head. In interview, dancers confirm this very claim. They say that when they mark they see the real thing or some specific part of the real thing in their head.

This raises an obvious question: how can dancers get anything *more* from marking than from mental simulation? We know that mental simulation can improve performance; it is a recognised form of practice. We know also that marking is essentially moving in a similar but nonetheless wrong way. So what extra can moving the body add to the good things that come from mentally simulating moving in the right way?, Indeed, why bother to move the body at all? Why not just sit still and mentally simulate the phrase?

To learn whether marking adds something beneficial to mental simulation, to show, in other words, that it is not just a movement epiphenomenon, like muttering when you think, or jiggling when you are nervous, we did a study that involved teaching three new phrases to ten super-expert dancers, all from the Wayne McGregor | Random Dance Company. The dancers were broken into three groups. One group practised their phrase by lying on the ground and mentally simulating it; another group marked it; and a third group practiced it by repeatedly doing it full out.

The procedure was this. All three groups were taught a phrase by a choreographer. After learning the phrase during a ten-minute period, each dancer was graded individually on how accurately they performed the phrase. Next, each group practised the phrase for ten minutes, using their assigned method: the three conditions of practicing full out, marking, or mental simulation. At the end of that practice period each dancer was graded again, and we calculated how much each had improved. The size of this improvement showed the benefit of practicing in a certain condition. Each group then changed its practice condition and was taught a new phrase. Accordingly, if group one marked when practising phrase one, they now practised phrase two by dancing it full out, and then later they would practice phrase three by mentally simulating the phrase.

When setting up the experiment we were hoping to find that marking was a more effective method of practice than mentally simulating a phrase while lying on the floor. That was certainly true, we did find that both marking and full out practice were better than mental simulation. But far more interestingly, and to our absolute surprise, marking was better than full out performance by a small but significant amount in most dimensions of assessment.

What does this show that is relevant to drawing and sketching? The conclusion we drew is that marking mediates thinking about the target – that is, a dance phrase – in a way that helps a dancer focus attention and project thought. When a dancer marks, it is easier for them to home in on timing or technicality or ordering of steps than when they try to work on everything at once, as they would were they practicing full out. Like making a lithic illustration, a dancer, by marking, can bring specific aspects of a complex thing into focus. First this curve, then this step. So marking drives attention to aspects of a structure or process in arguably the same way that having to draw a lithic stone drives attention to specific aspects of the stone. Marking, drawing and sketching focus attention.

Marking also teaches us something about the project create project cycle. One possible explanation of why marking helps dancers so much more than mental simulation is that the movement of the body may serve as a support for projection. This point is significant because in mental simulation dancers can also focus on specific aspects of a phrase. They can do the equivalent of sketch in their imagination. The reason they do not get the same benefits as marking is precisely the question at issue.

The answer, I believe, is that whereas imagination proceeds without any physical feedback, marking is a physical process that can help a dancer attend to things that receive immediate feedback. Many dance movements rely on playing with physical things like weight, force and rigidity. Without feedback from the body it is hard to imagine accurately what one needs to watch out for when falling, leaping, catching another, stiffening an arm.

To sum up, marking is a physical process in the world, like drawing and sketching. As such it serves to externalise; it provides a substructure or scaffold, like the grid in tic-tac-toe, that a subject can project onto. The reason a dancer can probe more deeply into a dance phrase by marking than by mental simulation is that marking provides the dancer with the right support to see the features (s)he needs to see. Imagination is more limited. It is virtually impossible, for example, to imagine the precise tipping point of a body. There are too many factors. But it is easy to feel that point when one is about to topple. Marking provides the basis for this sort of projection. It adds to imagination. Marking may offer the perfect compromise between doing it in the head and the world.

4. Conclusion

Drawing and sketching, like other forms of externalising thought, are often seen as aiding thought by providing a persistent structure to build on. In considering the interactive strategy of projecting-creating-projecting structure I emphasised that the value of persistence is as much to provide a kicking off point for the future as it is to record the past. Projection is an understudied process, and yet it may be at the heart of much human thought. It is easy to see its value in geometric problem solving, but it is general enough to be seen as a process throughout our active probing of the world.

This idea, that projection is an active or enactive process where we first impose structure and then typically create some aspect of the structure we just imagined, ties to lithic illustration. When paleoanthropologists draw a stone to structure how to scrutinise the stone their act of drawing can help them see the lines of 'making' in the stone. The physical action of drawing may make it easier to see how an early hominid knapper chipped away at a stone. As before, projection is a process that lets one see more than is there. It adds something. The lesson of lithic illustration is that the process of projection can be structured by rules of drawing. How to project the right structures can be taught and regulated.

The last phenomenon I discussed – marking in dance – pressed the idea that projection is more powerful than imagination because it can harness physical attributes like rigidity or stability that are only imperfectly available in imagination. Marking is a provocative case, halfway between inner mind and outer body where we do things in the body for their immediate effect on imagination. We dynamically shape the body to facilitate projection, which is essentially a way of shaping imagination.

It is dangerous to say that we can think better in the world than we can in imagination alone. Our discussion of projection suggests that the dichotomy is illusory. Whenever we act we facilitate projection; projection is just imagination tied to external structure. The challenge is to find better actions since these will lead to better projection – better imagination.

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Drawing and Visualisation Research

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Special Edition:
Drawing in STEAM

DRAWING TO AID RECOVERY AND SURVIVAL

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This paper considers the role of drawn visual communication materials and their effectiveness as a means of obtaining informed consent. The researchers used practice based 'action research' as a means of working with clinicians at the Liver Transplant Unit, Birmingham Children's Hospital, UK, in the preparation of materials (in this case picture storybooks) leading to medical surgery. The researchers' approach was designed to match the needs of the hospital and the nature of the investigation.

Keywords: drawing as non-verbal communication, medical problem solving, practice based action research, cognition, and theory.

INTRODUCTION

The physiological recovery of young children from invasive surgery at Birmingham Children's Hospital's (BCH) was of particular concern to its behavioural physiologists and play therapists. Professor Kelly identified the need within the Liver Unit to improve the quality of life in young transplant patients. Her team looked to creative approaches and solutions.

After initial consultation with the clinical team, designers Mario Minichiello and Liz Anelli decided that 'action research' methodology would be best to continuously inform the development of these creative materials.

IDENTIFYING THE PROBLEM:

Clinical data was gathered throughout the research, design and implementation process by BCH's medical team. Due to the hospital's ethical and data-protection policies we are not however able to publish the information within this paper. The components that relate to developing the research project and the resulting children's books are reported, but without reference to individuals.

Research conducted by this team identified the need to find new ways of communicating with children in the target age group (5 to 8 years of age) in order to prepare them for surgery and to ensure improvements in the recovery process. Visual communication, defined as 'communication that relies on vision' (Farlex 2012), was seen as the key method.

In collaboration with play therapists Liz Anelli wrote and illustrated narratives for two books to address these main patient age groups. A colouring book (with very few words) was designed for the youngest (new readers) group. Mario Minichiello designed and Liz Anelli illustrated a storybook for the older group with more detailed and complex narratives, which also had to acknowledge the different cultural backgrounds of the children. As Penni Cotton observes in the cultural role of children's books in Europe: "The most important aim has to be to communicate the similarities and differences between cultures through carefully selected visual narratives … "

The books would have the appearance of conventional children's books but the contents and design developed to:

1. Obtain informed consent from children facing liver transplant surgery (within established ethical measures developed by the hospital),
2. Understand from the child's perspective what were the main causes of concern in the pre-operative and post-operative process and address those issues.

RESEARCH METHODOLOGY

The information gained from the application of 'action research' methods guided the development of the book design process by creating a narrative that more accurately assessed and then addressed the children's key concerns.

The Research Method plan was cyclical:

Stage 1: Defining the problem: Initial planning used information from the behavioural play specialists and leading ward sister. The aim was to reduce the chance of shock or other forms of post-operative trauma by addressing key questions that arose from patient concern – these were broadly:

- Why am I here?
- Why do people here dress in that way?
- What will happen to me?
- What do the machines do?
- What happens when I am asleep in the operation?
- Will I be safe?
- When will I be better and when can I go home?

Stage 2: Action plan: Considering different approaches of addressing these questions or indicative areas of concerns. This included looking at creating games and perhaps specific toys that followed the child through their operation. Action research, as described by Mcniff, 'is a form of inquiry that enables practitioners in every profession to investigate and critically evaluate their work by producing accounts of their practice' (McNiff 2011).

The first stage was to develop storyboards as a generic part of any of these possible outcomes. The storyboard depicted different stages in the surgery procedure. They were used in the play schemes to set up scenarios and to prompt the child's interaction and evaluation through play.

Stage 3: Taking action after reflection and further planning. This lead to a number of refinements: written texts, picture book storyboard development and explorations into drawings of the characters (character development).

Stage 4: Evaluating actions taken: The children and family members worked with what is referred to as in industry practice as a pencil line drawn 'mock' or 'dummy book' which was developed from the feedback from initial storyboards.

Stage 5: Specifying learning contents: Purpose drove the initial visual hypothesis including the draft story. Context was further refined and developed through consulting, planning and action, repeating the cycle and continually refining the information. The final outcomes enabled children to understand and be informed as to the nature of their condition and the surgical processes. This enabled them to consent to the operations and in each case this consensual agreement aided their immediate recovery and enabled a better level of planning for the medium and long term management of their condition.

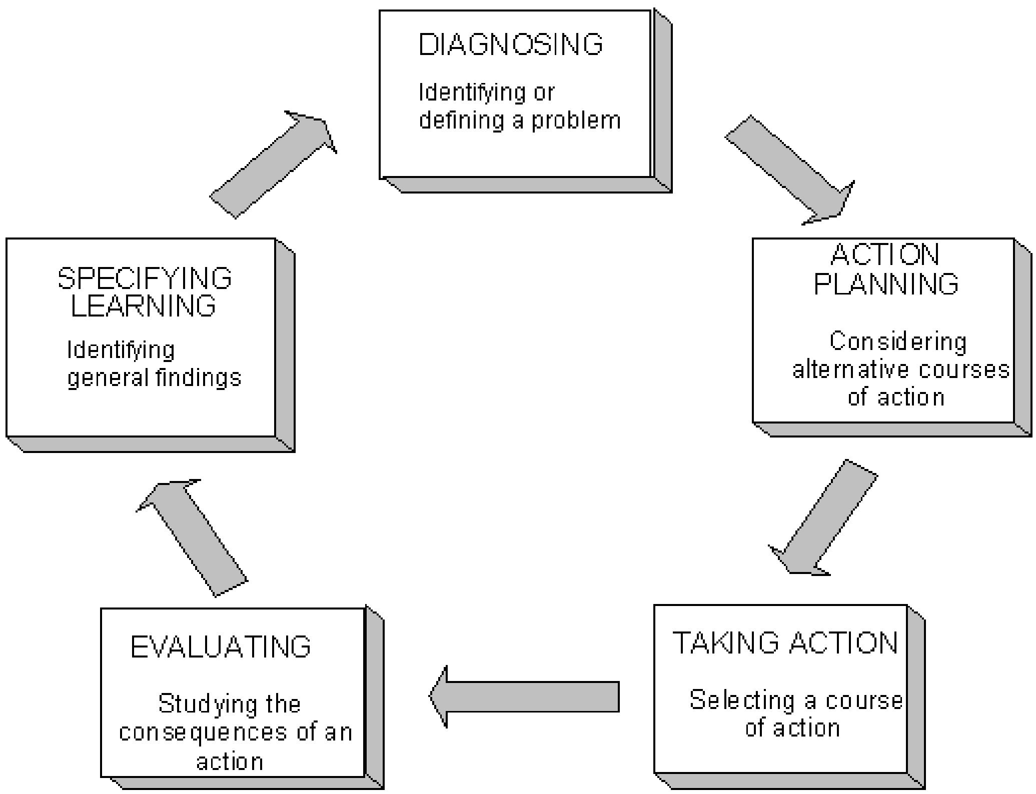


FIGURE1: DETAILED ACTION RESEARCH MODEL DIAGRAM (ADAPTED FROM SUSMAN 1983)

DEFINING THE PROBLEM AND CONSIDERING COURSES OF ACTION.

Drawing was used as a means of conceptualising and visualising throughout the project - in meetings, in play therapy sessions as well as for the end outcomes. The drawing process enabled child patients to think creatively about their questions and better express or debate them through the drawing process with clinical staff. This introduced a new way of thinking and as Ken Robinson suggests 'new ways of thinking can transform us' (Robinson 2001). To understand the data the team had to design a process of engagement around the key questions and the children's emerging drawn images.

Through their own drawings they were also able to share their concerns with members of their family and the other children in the Liver Unit. This enabled them to be part of a group and not to feel isolated or too home sick. As Berger observes ' the static image of a drawing, or painting is the result of the opposition of two dynamic processes.

Disappearances opposed by assemblage' (Berger 2007). Through drawing the children were able to 'reassemble' their homes and the things they missed.

Forms of verbal protocol analysis were used to identify significant issues and behaviours that might become a concern. This was in order to use the 'verbalisations of thoughts ' that children made during the deep levels of concentration occurring in and resulting from the drawing process.

Ericsson and Simon argued that the closest connection between thinking and verbal reports is found when subjects verbalise thoughts generated during task completion. When subjects are asked to think aloud, some of their verbalisations seem to correspond to merely vocalizing 'inner speech'. 'The verbal probe may be constructed to induce the subjects to generate information about the hypotheses under consideration' Ericsson and Simon (1993), which would otherwise have remained inaudible. 'Non-verbal thoughts can also be often given verbal expression by brief labels and referents' (Renkl 1997).

This is not intended as a detailed description of the child's cognitive processes but it does help to elucidate some of the drawn information. The extent of the verbal and drawn description of an issue reveals how deeply embedded or troubling it might be to a child.

SELECTING A COURSE OF ACTION:

The illustration brief which arose from this process, therefore addressed the following questions:

- Why am I here? How to visualise the journey from illness into recovery.
- Why do people here dress in that way? Remediating the appearance of things and people, in particular the human face when masked.
- What will happen to me? How to visualise the journey to recovery in detail, with positives.
- What do the machines do? Remediate machines and processes.
- What happens when I am asleep in the operation? Detailed explanations that have positive and caring overtones.
- Will I be safe? What did the child regard as safe?
- When will I be better and can go home? How to visualise going home and normality – not stigmatised being as different in the society of other children.

This information helped to develop the brief, which was to develop two children's books for different age groups to take the 'reader' through the detailed journey to recovery. The written and visual language and design of the books could not be ambiguous or inconsistent. There was a clear aim not to 'dumb down' either the process or concerns of the child. The approach taken was that the narratives would be designed to prepare the child for the realities of clinical procedure. However care would be taken not to overly instruct – the aim was to create an inspirational children's book adventure, not a medical manual.

BCH is an international hospital – English not always being the first language used. This was one of the challenges we faced but it also made picture storybooks with 'their cooperative balance of text and image', a natural solution. 'Picture books are a significant means by which we integrate young children into the ideology of our culture' (Nodelman Reimer 2002).

The visualised storyboards and stories became cognitive models, articulating through drawing a form of learning about a complex process that reassured the child and allayed their fears.

Through play therapy sessions the children raised a number of issues. For example, any masking of the face is immediately problematized by the relationship the child has in reading emotional information from facial expression.

In reflecting on the concepts behind children's book illustration and publishing, Minichiello/Anelli cites Piaget: 'As babies develop they respond to an increasingly sophisticated differentiation of the pattern of a face. They are progressively able to discriminate between the spatial order and shapes of facial features. This process is reflected in early years drawing development. Faces are vital to young children and they habitually draw them larger in proportion to bodies' (Piaget 2001).

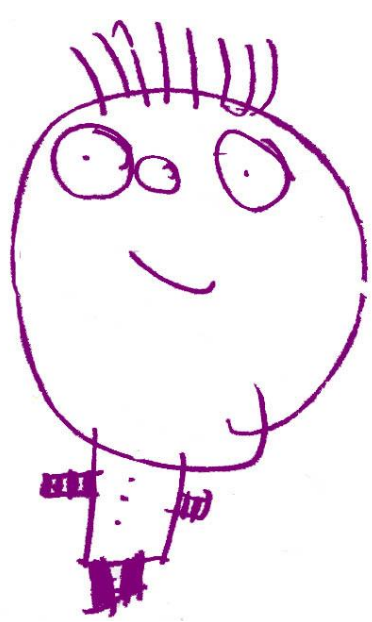


FIG 2: MINICHIELLO, C. *'DADDY'*. (*DRAWING PENCIL)*

Illustrations had to address this within the written/read textual narratives, the sequencing in the layout design and in drawing details. Even where the inclusion of a surgery mask was necessary it was possible to convey thinking and emotion by how eyes were depicted. The physical entity of a book enable time to be spent with each image, to absorb the masked face and reposition it in the mind as an element in the journey to recovery.

Another key concern was the depiction of home, familiar environments and objects both in the pages of the books and in the drawings surrounding the children in their hospital spaces.

This thinking was based on the best practices, As Thornton and Brunton observe at the Reggio Emilia centre in Italy; 'the quality of the environment in the infant- toddler centres and preschools is an important value of the Reggio approach. It plays an active role in how children play and learn'....(Thornton Brunton 2007). Placing these elements carefully within the storyboard enhanced the sense that each child was getting closer to going back home.

Furthermore the fear of being abandoned, being left, lost or in a strange place arose from the testing of the storyboard images. This fear is not helpful in the recovery process and can be a difficult issue to address. The repetitive re-telling of the stories became key in re-casting the operation theatre and recovery intensive care room as a magical space of healing – 'reality adjustment' as the last phase of a child's "magical thinking". Piaget contends that this is the beginning of maturation (Pearce 1974).

Habitual usage gave another reason for picture books to be a viable solution for benefiting informed consent. Story-time within families often follows set patterns with the same books being selected as part of a ritual. This meant that the Liver Books would become inculcated into the families' shared knowledge, of vital importance when it is considered that a liver operation is by its nature an emergency procedure that depends on the death of another patient and a rapid response by medical staff and receiving family alike.

STUDYING THE CONSEQUENCES OF ACTIONS TAKEN

The child feared being removed from home and the loss of their emotional connection to objects, situations and people but most of all to a detailed memory of themselves and their bodies. This presented an interesting dichotomy between how they remembered and drew themselves and how the operation changed their appearance.

The cognitive challenge was to present the narrative journey as a means of considering the relationship between being 'unwell' and being cared for and supported, to being 'back to their normal selves' as the person that they had originally visualised.

Drawing is one of the earliest forms of self-expression that children develop in order to make sense of the world and their place in it. This is well documented in 'early years' development research, which supports the use of picture storybooks to encourage and consolidate learning. Pictures plant the seeds of learning and encourage children to think creatively and positively about their future. Drawing their own pictures allows children to explore the ideas they have encountered, including difficult issues and themes.

The aim of engaging with the concerns of the children through their own drawn images enabled researchers to better modal and develop the people drawn in each of the books – and to ensure that the main character design provided an empathic modal through which the children could begin to consider the differences between reality (how things are) and the imagined worlds (how they might be), 'pictures and artefacts around the setting to act as starting points for children's creative expression' (Thorton Brunston 2007).

It is here the questions about the body had to be addressed. The process of liver transplantation is extremely physically invasive. This reality became more clearly understood through the storyboard and raised many concerns among the children and their parents (some parents expressed the view that this aspect might be best not discussed and visualised so openly). This would have simply compounded the problems being encountered in postoperative recovery.

The results of this thinking and data suggested that the images needed to be recast into a positive narrative with an achievable outcome that the child would believe. Key motivational factors are reiterated through the design of the books. These centre on the character of Anita and her journey through the liver transplant surgical processes.

As a consequence of their operations the children have to encounter new devices that become part of their bodies. These devices change their bodily functions and interfere with intimate day-to-day interactions such as handholding, drinking fluids and removing fluids from the body. Therefore the focus of each illustration increasingly became concerned with ways to mitigate the potential for shock or the unknown.

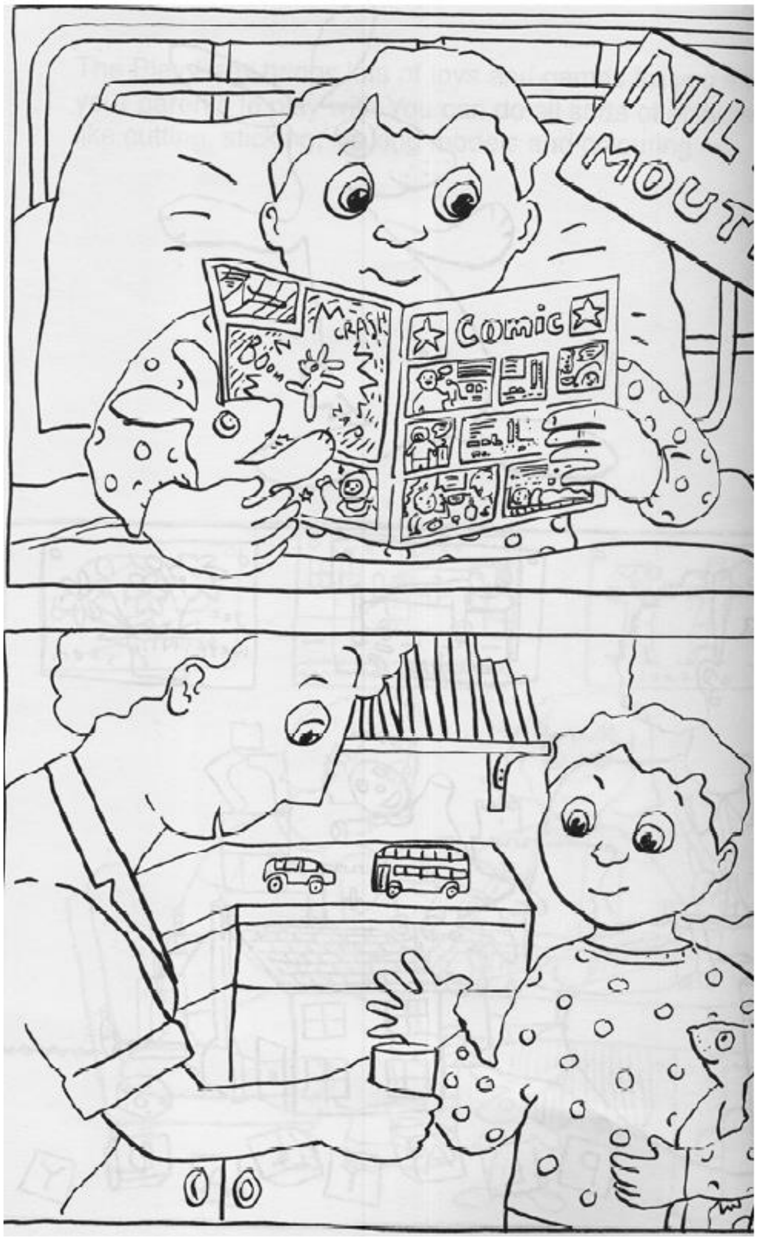


FIG 3: ANELLI, L., 2002. PREPARING FOR THE EXPERIENCE –THE PRE-MED GIVEN BEFORE AN OPERATION. (PEN DRAWING (297 X 210 MM)

In the ‘New Liver Colouring Book’ the child colours in the line drawings and explores what is going to happen to him both through the Imagery and with the psychologist through directed play.

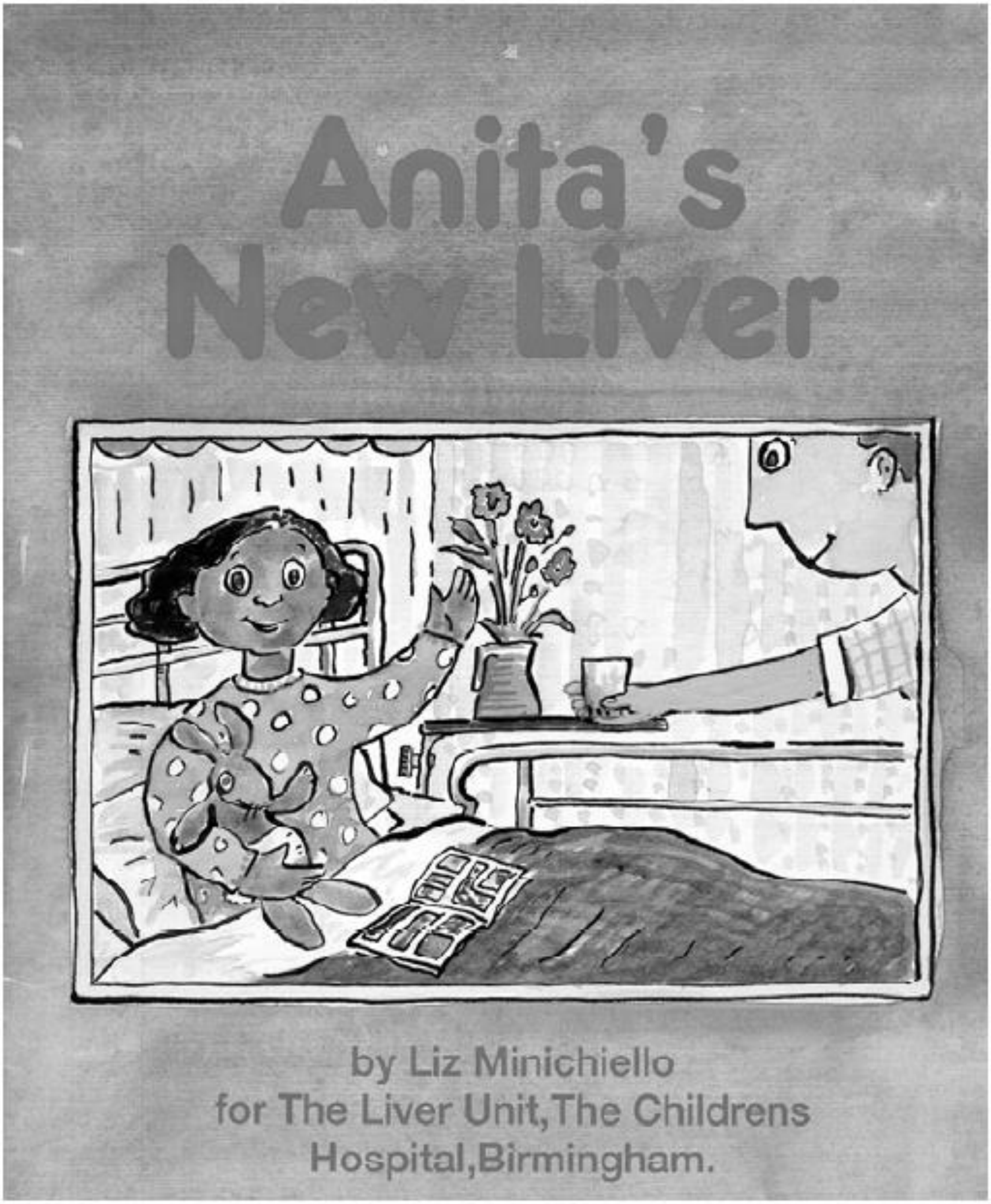


FIG 4: ANELLI, L., 2002. ANITA'S NEW LIVER COVER (PEN DRAWING WITH WATER COLOUR WASH) (260 X 210 MM)

The storybook for the older child as part of the preparation to gain the child's informed consent, read as any other picture storybook.

As part of the process, research into contemporary children's books was undertaken to compare best practice and this revealed significant areas that might aid the team in explaining difficult concepts.

Many modern illustrators and writers have used key words repetition (the early Ladybird Book school reading schemes or the more palatable Doctor Zeus 'Cat in the Hat' series), word association and phonics. Integrating words and images builds visual comprehension and reading skills. Words and pictures in sequences animate meaning and prompt memory. As Stefania Tondo states in her thesis, '*A wonderland of pictures of Alice from Italy',* this is in effect 'a desire to translate the surrounding world into a more pleasurable language. It is also a desire to escape from the kind of book without pictures and conversations that young children might be threatened by…'(Tondo Harding Pinsent 2008).

In creating different imaginary situations the play therapy researchers were able to test the different approaches of some of these other children's books, juxtaposing them to emerging behaviour patterns. Some of these behaviours are long recognised as a part of the child's development and these are reflected in the 'cautionary tale'. Cautionary tales (traditional folk tales and the stories of Grimm, Anderson, Belloc etc.) have been a long established means of instructing children into the adult world and dealing with difficult issues. *Not Now Bernard* by David McKee proves to be a useful reference point. McKee's book deals with a child's anger, the monster that fear can develop into. This is a prime example of a narrative that is intended as much for the parent as it is for child. Here an ignored (perhaps unloved) child becomes the monster.

The ability to read relevance into the relationship between text and image leads to the leap of reader interaction, expectation demanding and thus stimulating higher cognitive awareness. Creative thinking allows the child to imagine a better outcome and understand their role in providing their consent. Creativity is 'the ability to see problems in new ways', 'to see things from a new perspective', and 'the knack of looking for answers in unexpected places'. The dictionary defines illumination as '*throwing light on a subject in order to see it better'.* Words used for clarity of thought: *insight, foresight, hindsight,* and *clear-sightedness* all contain visual reference. (Edwards 1986)

This means that the child can 'ask' and this asking can emerge through play and through the child's own drawings. Child psychology says much about the primacy of drawing and 'visual literacy' but how can this be developed and used to resolve a particular medical challenge and improve recovery from major surgical procedures? What approaches can be developed through medical and illustrative partnerships to create new ways to compensate for the lack of verbal expression in young children? How can 'creativity' expressed through drawing be used to communicate to young children facing major surgery ways that allow them to visualise a better future?

The consequences of these actions essentially addressed the underlying concern of how a drawn narrative can help a child (and their family) face the reality of a potentially life-threatening situation. How can they 'envision' their place in the world when their place in it is not assured? When their survival is contingent on the care and action of others? It highlighted that when children have internalised and accepted this, they can consent to be helped through this difficult journey, and that they can in length return to normal lives. By continuous exposure through a supportive team of people, difficult ideas can come to be regarded as a normal part of dealing with illness and an aid to their recovery.

IDENTIFYING THE FINDINGS AND NEW KNOWLEDGE

Actions taken had addressed questions raised in children's study groups, further assessed through the use of the picture books by the play therapists. Studies had disclosed how operational equipment and instruments had become fearful objects. The approach taken in the books' design and illustration therefore avoided misleading the child about the nature of the procedures involved. By not taking a comical or cartoonist approach the researchers were better able to represent the true nature of surgery.

The Liver Unit had presented some interesting challenges in its highly specialised care, communicating with twenty-four different specialists within the Hospital. Established parameters were that the language of texts needed to be medically accurate but at the same time easily understood, thus paving the way for imagery to take prime place.

The rationale was to achieve three things: firstly, to address informed consent; secondly, to prepare the child (and family) for the realities of surgery and finally - to address the difficulties of post-operative reaction to the trauma of surgery and living with an on-going condition. Hospital-based play therapy around the guided use and then home ownership of the set of books were key to all three.

The design and illustration of both books reflected the key aspects of other contemporary illustrated books. These particularly rely on drawing for their impact and the fact that handmade images provide encouragement for children to engage in developing narratives through their own drawings made about the books they read. Even a brief look at any primary school wall reveals this process. Drawings have recurring themes such as loved objects of comfort and affection, soft toys, pets, a depiction of home, a clear sunny sky.

Drawing and drawn books enable children to encounter difficult aspects of our world within the safety of their imagination and the small focus of a hand-held book, on a par with other familiar toys. Examples of this can also be found in the cannon of contemporary children's books such as in John Birmingham's book, *Granpa*, which deals with the death of a loved one. It has an unsentimental realism that gets to the heart of the matter.

Engaging with the action research methods resulted in turning very detailed and technical medical information into a fully mapped out storyboard, developing key characters and a detailed picture/word story. Throughout three months of work content was controlled by a series of meetings and dialogues concerning portrayal of every aspect. As the creative team, we sensed that our visualisation methods during these sessions prompted greater and more enthusiastic support across the diverse medical teams. Both sides of the team (medical and creative) appreciated the dexterity of the drawing language and the deep power of a book author/illustrator's imagination to enable problems to be overcome quickly and with good humour. All aspects were thoroughly tested by play therapists for simplicity and ease of use. Even the shape and size of the books wee altered to being more easily portable, part of the families' essential 'going into hospitable' kit.

The advantage of using illustration, the drawn image, allowed what could have been horrific, through the graphic reality of photography, to become acceptable. The design of 'difficult moments' was particularly carefully thought through with all the team at the hospital.

Fig 5 demonstrates the flexibility of illustration allowed us to show not only what was happening but also what individual characters were thinking. Compositions could be selective and softened within the language of the illustrator.

The world of the hospital was made a happy and bright place, positive outcomes

assured and people reassured. The books' textual and image dialogues combined to encourage leading questions from the reader enabling the hospital staff to discuss all issues, no problem too big or small, a major part in ensuring recovery.

This was an impact practice-based research project that highlighted the use and power of the drawn image to work within the imagination and project the child's thoughts towards a better future. Verbal feedback from the hospital verified significant improvements in the children's reactions and abilities to accept the initial impact on their appearance of liver transplant. This resulted in better family experience and consequently more positive recoveries. To use what has now become a cliché, in this instance 'a picture did serve to speak a thousand words' (Barnard 1927)

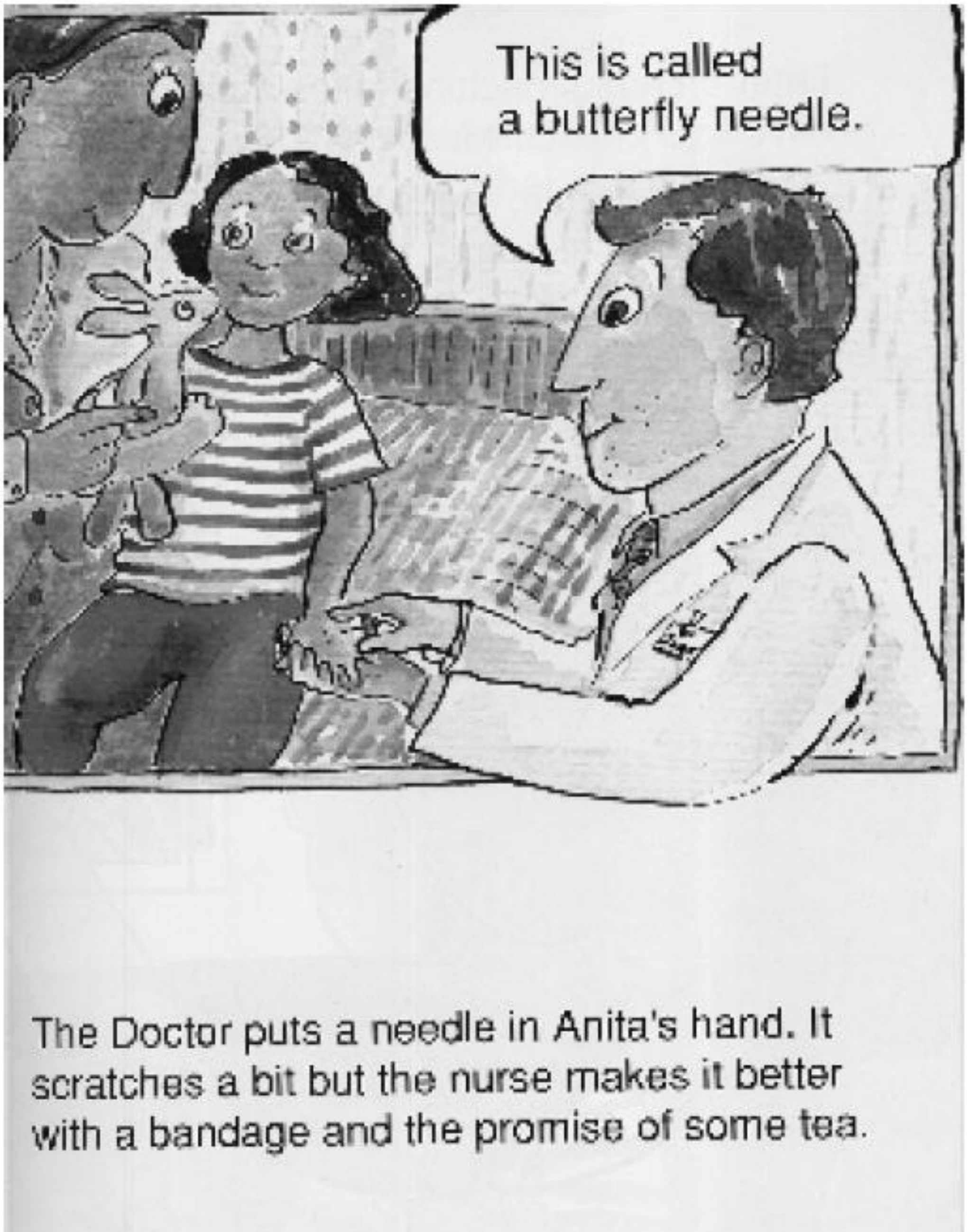
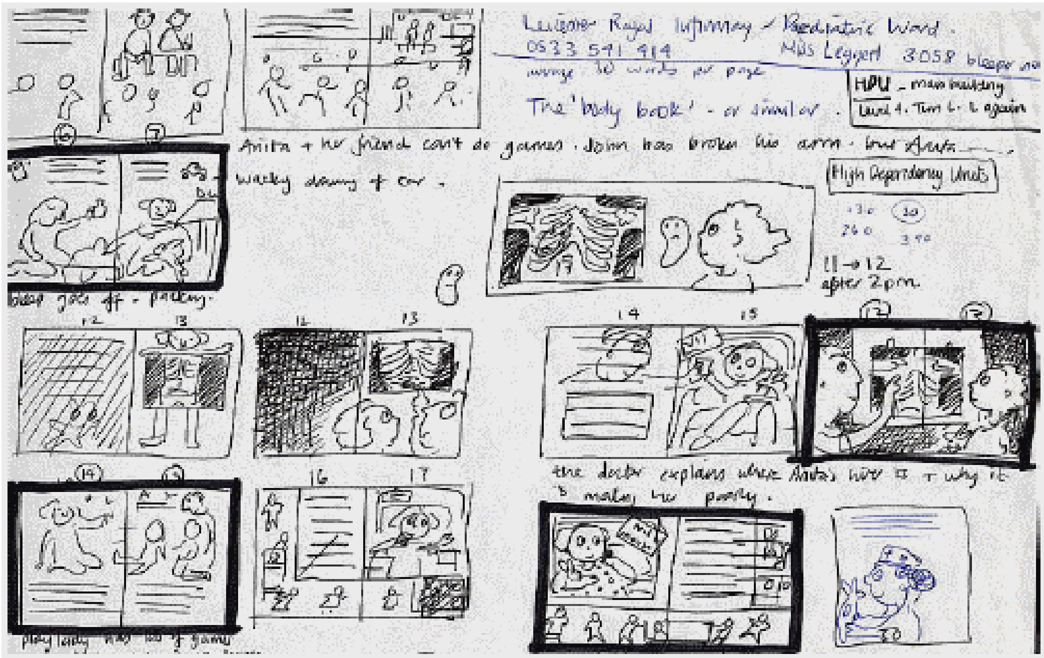


FIG 5: ANELLI, L., 2002. *PRE-OPERATION - THE BUTTERFLY NEEDLE.* ANITA'S NEW LIVER (PEN DRAWING WITH WATER COLOUR WASH) (260 X 210 MM).



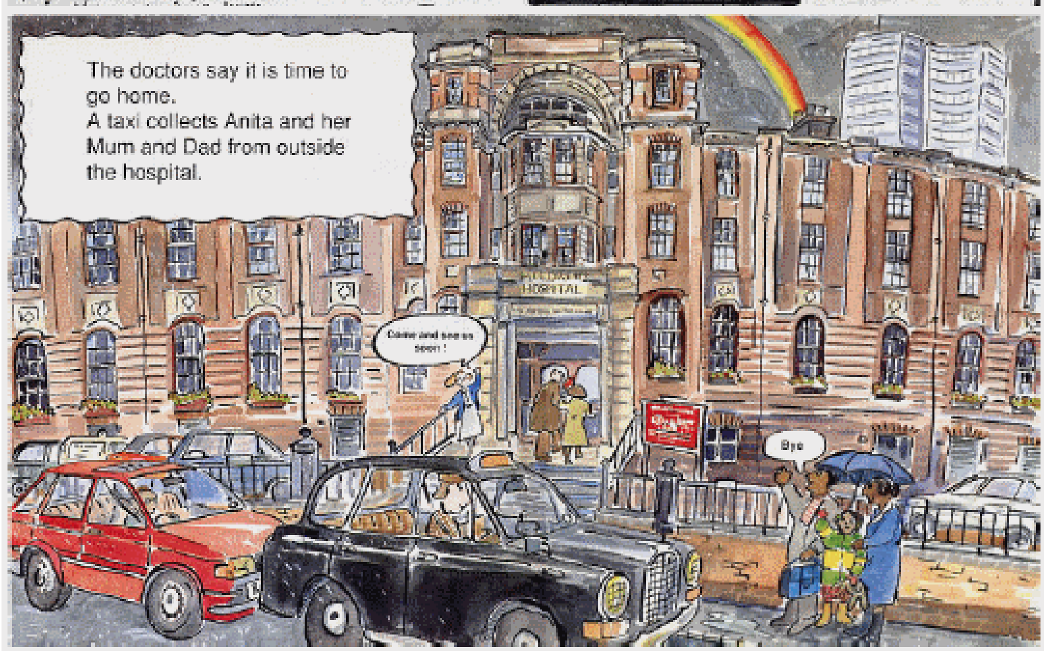


FIG 6: ANELLI, L., 2002. EXAMPLE OF THE FLEXIBILITY OF THE LANGUAGE OF DRAWING, ON-GOING PROCESS OF ITERATION, EXPLORATION THROUGH THE STORYBOARDING PROCESS. (DRAWING) (420 X 260 MM)

FIG 7: ANELLI, L., 2002. GOING HOME WELL AND HAPPY. ANITA'S NEW LIVER (PEN DRAWING WITH WATER COLOUR WASH) (420 X 260 MM)

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Special Edition:

REPRESENTATIONAL EFFICACY AND ERROR DYNAMICS IN OBSERVATIONAL DRAWING: A QUANTITATIVE METHOD FOR DRAWING ACCURACY EVALUATION

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This paper presents a quantitative method for assessing observational drawing accuracy, as a more objective alternative to evaluation by expert panels. The method, design process and testing revealed insights about representational efficacy and error dynamics which may inform teaching and research.

The method was used to assess and compare the efficacy level of apprentices drawing the same subject. It involves disassembling shape into partial aspects – using four graphic properties - that influence the overall representational efficacy, and comparison to photographs taken from the draughtsman's viewpoint.

This process has proven useful to: a) distinguish which parts of the drawing are accurate; b) specify the formal aspects that compromise representational accuracy, and to what extent, and; c) identify and quantify types of error. The research extends existing methods and is comprehensive in detecting 2D representational errors.

The findings also suggest that certain kinds of error can give rise to others, based on some kind of "logic of compensation" process that might happen unconsciously during the task. This deserves further research.

INTRODUCTION

Recent interest in the human perceptual process shown by the neurosciences, psychology of perception and cognitive science in general has brought to the drawing theory field new data and new theories that have attracted enormous interest and are an opportunity to revise concepts and question some of these field's paradigms and beliefs.

In this context, the referential function of drawing that during the twentieth century we saw almost doomed to oblivion now re-appears on the agenda, finally freed from the unjust burden of academicism and traditionalism. Furthermore, we face the result of over a century of modernist teaching with its iconoclastic matrix: a growing "visual illiteracy" that begins to make itself significantly felt in younger generations, demanding answers not only from the scientific community but also from education. In response to this need for answers, basic observational drawing (drawing from life) re-emerged from amongst the myriad of possibilities offered by the giant field of drawing, and began to get more attention. Still, there remains many questions about representation and in particular, how to evaluate it in light of contemporary issues in art. This article, based on the author's Ph.D. research (Pelayo 2009), provides some frameworks for looking at and more objectively assessing observational drawing, specifically of the human figure.

Observational drawing calls for three distinct entities, namely a) the draughtsman, b) the entity being visually represented, and c) the graphic traces themselves. The process of making a drawing from life results in a single graphical object, but it refers, not only to the thing represented but also to all three entities simultaneously. Moreover, a distinction can be made among these three levels of meaning that can be decoded in terms of: a) information on the subject whose existential momentum is projected in the image and to which we commonly refer as "expression", b) the abstract information of the artwork itself on the support, and c) information relating to the representation of the thing being represented.

From these several possible concerns, my research focused exclusively on "representational efficacy" a term used here to describe the result of drawing only regarding the thing being represented. The term purposefully leaves out the remaining levels of representational drawing. In fact, the reference information of this type contained by the drawing can be more or less coherent and may have different levels of accuracy, depending on the draughtsman's perceptive capacity and representational skill. So, the effectiveness of a representational drawing refers to the level of assurance shown by the drawing in reference to the thing that is represented.

Assessment of representational accuracy in drawing is an issue that follows the emergence of psychology and has been used in intelligence or psychological tests and experiments since the beginning of the 20th century until today. It can also be found in studies about drawing skill or art skill in the areas of psychology or art teaching (Cain 1942). Generally, in this literature, two kinds of processes are used to measure accuracy. There are more subjective tests that assess the image's generic wholeness, without specifying the items that are at stake in term of drawing accuracy (e.g., Konecni1991; Cohen and Bennett 1997; Cohen 2005; Kozbelt 2010). Then there are tests that are quite objective and also very specific about one or two singular aspects within the drawing. (e.g., Paulsson 1929; Cain 1942; Carson and Allard 2013).

The first kind of assessment process consists of inviting specialists to perform as critics to rate accuracy between drawings, or to compare each drawing with a photograph of the model. Variations are used, like recruiting volunteers with no formal training in visual arts and augmenting the number of reviewers. As Cohen (2005) points out, this kind of process poses various problems: sometimes it is difficult to recruit experts, especially to form large groups, and it is also unclear on what objective basis one defines an "expert," considering that "experts" can have different definitions of "accuracy."

The alternative in qualitative evaluations on ordinal scales by multiple critics is recruiting novice critics. That option offers the advantages of relatively easy availability of novices compared to experts, combined with the fact that their abundance reduces the effect of personal biases. The obvious disadvantage is that these critics have no recognised expertise in the area even though it has been claimed that people in general are capable of perceiving/judging pictures.

The second process is quantitative and consists in measuring certain aspects of drawings. These processes extend beyond general resemblance of subject-matter to an exact duplication of the model, assuming that a drawing is intended to be an exact copy of the model. Various ways have been used (Cain 1942) to assess the amount of difference between copy and model through exact physical measurements using measuring instruments: protractors to measure angles or directions of lines; rulers to measure height and width of lines; cartometers to measure curved lines' length; planimeters to measure enclosed areas of lines. Also more ingenious ways include targets of concentric circles to locate certain points and cross-section squares to locate areas borders.

The processes used depend on the measuring instruments available, ignoring the model's specificities of form or the nature of graphical implementation of the drawing. If these strategies have proved of some use in assessing simple 2D geometric shapes, they have also shown serious limitations when dealing with complex forms and/or organic ones, namely due to the reduction of measurements to three or four selected graphical cases, while reducing the focus of analysis (e.g., Konecni 1991) calling into question the degree of generalisation assumed by the test. In general, one can object that these methods are focused on the possibilities of the measuring devices, not the drawings themselves.

A recent experiment of this kind is a good example to illustrate the problem. Carson and Allard (2012) used angle-drawing accuracy as a way to measure drawing expertise. For the sake of economy, only three angles were chosen, and, for generalisability, the angles were chosen to sample abstract angles properties (acute and obtuse, non-overlapping, and how far certain angles are from others in the drawing). They do not take into account the drawing's more complex properties. Nonetheless, they stated that "the most fruitful insight from the drawing analysis is that: Drawing error is not uniform across the image" (Carson and Allard 2013:128) and claimed that error has to be looked for both globally and locally, investigating where error is greatest within the image.

The process we propose here tries, precisely, to address the problems noted above. It is designed to analyse the drawing both globally, in terms of the complex form structure, and locally, in terms of the error locations. It also performs this task in a comprehensive way, by looking for all error types, be they an angle, a width, or another form property.

Once the drawing is assessed through a global method as well as a local one, we can say that the assessment is no longer explicitly about accuracy, but about representational efficacy. Similarly, the drawing is no longer regarded as merely a copy but as an intelligent assemblage of visual information cues.

METHODOLOGY

To assess the representational efficacy level of observational drawings with a jury or taking measurements, it is usual to use a photograph of the model to develop a comparison with the drawings. Our method also used photographs of the model, taken from the viewpoint used by the draughtsman to register the same light pattern that served as input to the perceptual process that led to the completion of the representational drawing.

The experiment was done in 2005/6. The participants were first year architecture students at Faculdade de Arquitectura da Universidade do Porto (FAUP) attending drawing classes of Desenho 1. All of them had twelve years of prior schooling, and were between 17 and 20 years old. The four drawing sessions used in the experiment took place in the normal course of the drawing lessons and were conducted by the usual drawing professor, also the researcher. In each experiment session, the same ten participants simultaneously drew the same model for 20 minutes: 1st and 4th sessions: a cocksfoot armchair using graphite on A3 paper; 2nd and 3rd sessions: human figure standing (écorché 3D sculptural model and live nude model) in charcoal on A3 paper.

The participants were instructed to draw the model as accurately as they could. Also, they were told not to use an eraser and to draw in scale corresponding to the paper size. Ten drawings were produced in each session and, at the end, participants were asked to take a photograph of the model from the same viewpoint as the drawing. Ten digital photos and ten drawings resulted from each session giving a total of forty drawings and forty photos for analysis.

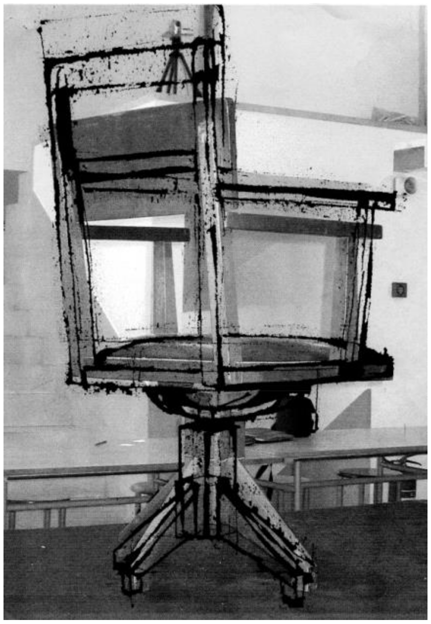


ILLUSTRATION 1. OVERLAPPING DRAWING AND PHOTOGRAPH

Then, the drawings were digitalised and the opaque background of the drawings was digitally manipulated to become transparent. In this way, the drawn image could be superimposed on the photograph, matching the model. A manipulation of the pictures' scale was also undertaken so the two images matched. However, the excess information in the drawings (multiple lines, auxiliary lines, textures, stains, line intensity variations and line thickness) as well as in the photographs (color, texture, tone, brightness and other forms in the visual field) prevented an exact comparison of forms as they could hardly be distinguished. As a result, the researcher concluded that it was impossible to obtain a clear simultaneous viewing of the double information, concerning the model shape from the two sources.

To overcome this problem, we chose to isolate the formal information from all the other information relating to other types of surface properties, the drawing construction or the graphic expression. This was done by a selective sampling of the images' graphic shapes, redrawing them in overlapping sheets of paper using a light table. We used fine pen, black in the drawings and red in the photographs, keeping the line width constant. We also introduced in the new images two axes, vertical and horizontal, corresponding to the maximum height and maximum width of each drawing, in order to facilitate subsequent scale adjustments.

ILLUSTRATION 2. OVERLAPPING REDRAWN DRAWING AND REDRAWN PHOTOGRAPH

The resulting images were contour drawings that look similar to each other, exclusively presenting the form variations. These images were targeted by the same digital operations previously attempted without success. The new images made the process feasible, i.e. they allowed a comparison between the drawing and the photograph by overlapping the two images providing the needed clarity of formal visual information coming simultaneously from the two different sources.

Experimental analysis was then carried out with the images collected in the first session drawings and we noted that a part, let us say an arm, of the represented chair could be very similar or not similar at all, depending on the orientation of the overlapping images. We also found out that the layering of parts, one's anchoring in already drawn ones, affected the starting points of each new model part added to the drawing. In this context it was clear that a part size could be right but its direction in the 2D paper could be inaccurate. Thus, that specific shape could not be considered all wrong. We therefore concluded that the method in question, designed to assess the drawing errors globally, had not only to deal with a specific analysis of each part of the represented object without losing their articulation in the drawing unity, but it also had to consider each kind of error.

In order to do so, we started to base our work in RBC, the recognition-by-components theory, or geons theory, mostly developed by Irvin Biederman (1987). This computational theory of visual perception, also known as "generalized cylinders" or "generalized cones theory" is somehow inspired by gestalt school ideas, especially the idea that human vision organises object shapes in terms of parts and their spatial relationships. This theory has been proposed by David Marr (1982) as playing an important role on object recognition processes in an object-centered coordinate system. The RBC has already been used in drawing research (Van Sommers 1984).

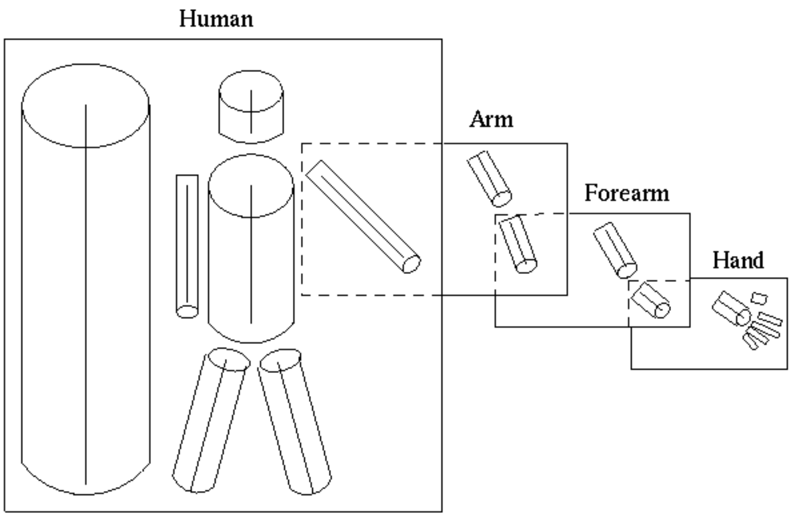


ILLUSTRATION 3. GENERALISED CYLINDERS FROM DAVID MARR (1982)

According to RBC, we are able to recognize objects by separating them into geons, which are the object's main component parts. Biederman suggested that geons are based on basic tridimensional shapes (cylinders, cones, etc) that can be assembled in various arrangements to form a virtually unlimited amount of objects (Biederman 1987).

Previous to the analysis, we decomposed the model's complex form into components. For instance, a chair is a complex shape that can be decomposed into simpler parts (backrest - seat – arms - legs). When the resulting parts were still not simple enough to draw and measure accurately, a new round of shape decomposing was done, until we got very simple figures of only one part (e.g. backrest, right support, left support). For the purposes of analysis, each of these parts was considered not as a 3D cylinder as in RBC but as a closed 2D form presented both by the drawing and the photograph.

The chair that served as a model was decomposed into sixteen simple component parts and the human figure into seventeen component parts. This component decomposition allowed us a very specific analysis of each part of the represented object, without losing their articulation in the drawing unity. This assured that both a global and a specific search for errors could be implemented in the drawing analysis.

Then, in order to discover the kind of errors shown in the drawing, we needed to distinguish the basic form properties all simple forms exhibits. That way, we could look for specific form inaccuracies in each simple part previously established. Those emerged from accuracy measurement literature and from our practice of teaching and drawing. Previous research focused mostly on measuring angles (Carson and Allard 2013), considered here as "orientation" and measuring distances between certain forms or graphic marks (Konecni 1991), considered here as "size".

Focusing on simple shape (geon-like) properties, our categories were then established corresponding to four different structural properties in order to allow the analysis of differences between each form property in the drawing and the photograph.

The considered simple closed form properties are these:

- Size - axes implied to any closed two-dimensional simple shape corresponding to the greater width and greater length.
- Orientation - the direction of the major axis implicit in any given two-dimensional closed simple form in relation to the paper's vertical and horizontal axis.
- Relative position – location of the joint between two parts, affecting both.
- Configuration - specifics of the figure in respect of its contour. What is commonly called form (e.g. a square has a setting other than an oval).

This then led us to detect different types of form lesions or "errors": if any part size in the drawing was not in accordance with the size of the same part in the photograph; if the orientation of any part in the drawing was not in accordance with the size of the same part in the photograph; if the relative position of any part in the drawing was not in accordance with the relative position of the same part in the photograph or if the configuration of any part in the drawing was not in accordance with the configuration of the same part in the photograph.

To each of these four formal properties was assigned a value of 0.250 of the total (1). This value was given to each part of the global complex form, only in case of fair similarity between a given part of the drawing and corresponded part in the photograph. The value of 0.125 was given to parts in case of a partial match and 0 in case of clear lack of coincidence between the parts to the property under consideration. One table for each drawing was elaborated with the resulting data. Thus, a figure with 16 drawn parts that scored 16 in representational efficacy meant absolute coincidence between input and output of the drawing process. Comparative analysis of the forty drawings with the corresponding forty photographs was carried out by the researcher using the methodology described. Comparison was conducted using the digitalised images and, when needed, moving the top drawing image freely over the photograph image. Each preset part was analysed considering the four formal properties referred to above.

RESULTS

The analysis resulting from the comparison between the simple component shapes, in the drawings and the photos, revealed both similarities and deviations in the same drawing, depending on the parts of the object represented and the form property considered.

To compare the scores of drawings with different number of parts, the values were translated into percentages. The average representational efficacy in the forty drawings was 68% for a standard deviation of 32.9, being the minimum value 39% and maximum 89%. The analysis of the level of effectiveness of the representational shape properties showed that the size and configuration were the least well controlled properties in general, showing levels of accuracy of 60.2% and 59.5% respectively. Levels for orientation and relative position stood at 75% and 74.7% respectively.

Participant:	7				
Drawing:	2				
	SIZE	ORIENTATION	Rel. POSITION	CONFIGURATION	TOTAL
Backrest	0	0	0	0	0
backrest support 1	0,25	0	0	0,125	0,375
backrest support 2	0,125	0	0	0,125	0,375
seat- side 1	0,125	0,25	0,25	0,125	0,75
seat- side 2	0,125	0,25	0,25	0,25	0,875
seat cushion	0,125	0,25	0,25	0,25	0,875
arm 1	0,25	0,125	0	0,25	0,625
arm 2	0,125	0,25	0	0, 25	0,625
arm support 1	0,125	0,25	0,25	0,25	0,875
arm support 2	0,125	0,25	0,25	0,125	0,75
metal piece	0	0,25	0,125	0	0,375
column	0	0,25	0,125	0,125	0,5
leg1	0	0,25	0,125	0,25	0,625
leg2	0	0	0,125	0,125	0,25
leg3	0	0,25	0,125	0,25	0,625
Totals	1,5	2,625	1,875	2,5	**8,5**
Efficacy percentage					**57%**

ILLUSTRATION 4. REPRESENTATIONAL EFFICACY ANALYSIS FROM EXPERIMENT 1

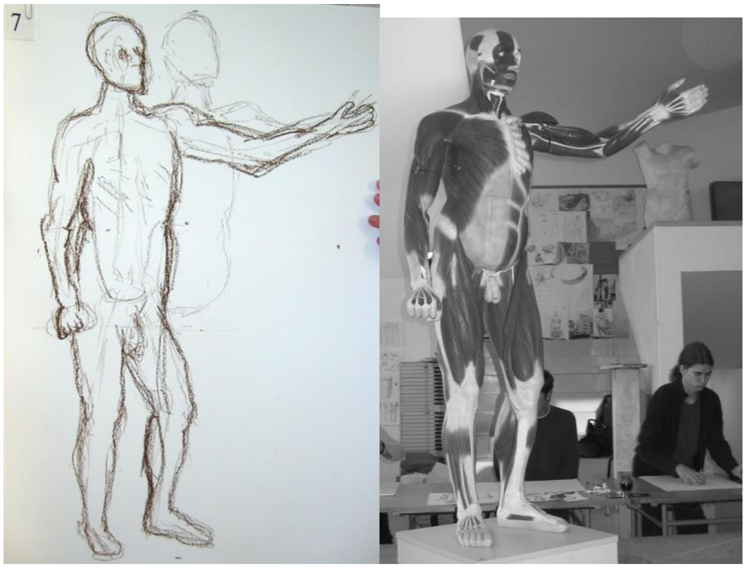
The score achieved by each participant showed two extraordinary cases, in which the total representational efficacy achieved was well above average (84.2% and 79.4%). Another divergence of those participants when compared to the others was that, while the relative position and orientation was near the average, slightly rising (80% to 73.4%), the shape properties' size and configuration in these two cases far exceeded the average performance of the remaining participants (83.4% to 53.9%). We may conclude that the reason for the high level of efficacy of these two exceptional performances comes largely from controlling the size and configuration, capacities that allowed an identical good level of control of the other properties, resulting in a harmonious management of all properties of the form, equally.

Since the best performances in terms of representational efficacy showed very close levels in all the formal properties and the worst performances revealed precisely a greater distance in pair size/configuration, it seemed possible that there were close links between the types of deviations and therefore some kind of error dynamic going on in the drawing process.

In order to study these dynamics in more detail, we analysed data from the first ten drawings representing a chair, because this was the drawing that showed major gaps in the performance of the different participants. This allowed us to arrive at more detailed verification of events, looking after possible links between types of error.

The configuration errors corresponded to a lack of detail in graphic forms, therefore they could have resulted from a lack of time to specify particularities. Therefore, we believe that they did not derive, in principle, from other type of errors. However, the remaining error types concerning all the other form properties are possible indicators of new errors in the drawing implementation process. We had already seen that the pattern is the prevalence of errors in size, accompanied by fewer errors in orientation and relative position.

Of these three error types, we could distinguish serious from partial errors. The total number of error in this sample of ten drawings was of 195; 94 of those were serious and 101 partial, which is a negligible difference of 7 errors.



Participant:	7				
Drawing:	2				
	SIZE	ORIENTATION	Rel. POSITION	CONFIGURATION	TOTAL
Head	0,125	0	0,125	0	0,25
neck	0	0,25	0,125	0,125	0,5
ears, nose, eyes, mouth	0,125	0	0,125	0	0,25
chest	0,25	0,25	0,25	0,125	0,875
basin	0	0,25	0,25	0,125	0,625
arm1	0,25	0,25	0,25	0,25	1
forearm1	0,25	0,125	0,125	0,25	0,75
hand1	0,25	0,125	0,125	0,125	0,625
arm2	0	0,25	0,25	0,125	0,625
forearm2	0,125	0,25	0,25	0	0,625
hand2	0,25	0,25	0,25	0,125	0,875
thigh1	0,25	0,25	0,25	0,25	1
leg1	0,125	0,25	0,25	0,25	0,875
foot1	0,125	0,25	0,25	0	0,625
thigh2	0,125	0	0,125	0,125	0,375
leg2	0,125	0,25	0,25	0,25	0,875
foot2	0,25	0,25	0,25	0,25	1
Totals	2,625	3,25	3,5	2,375	**11,75**
Efficacy percentage					**69%**

ILLUSTRATION 5. REPRESENTATIONAL EFFICACY ANALYSIS FROM EXPERIMENT 2

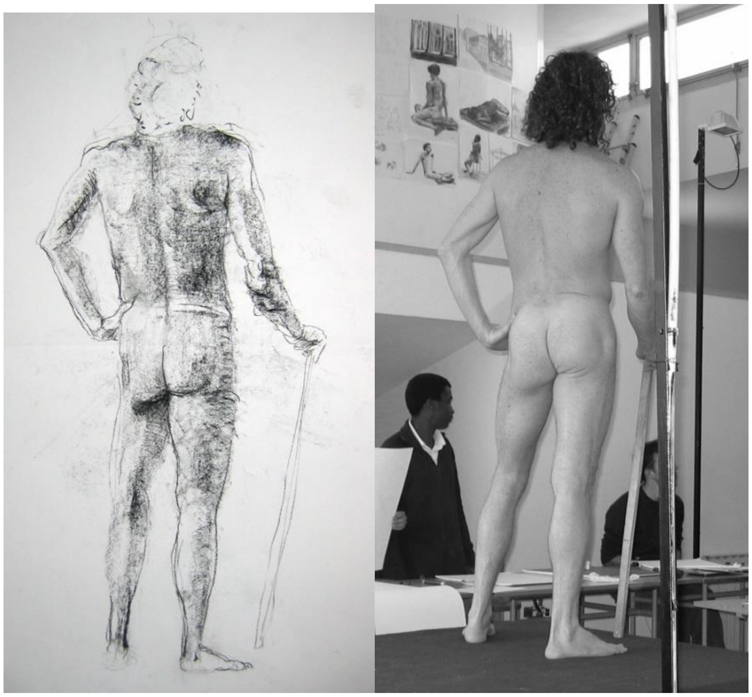
This smaller sample, in terms of representational efficacy levels, was equivalent to the forty samples showing predominance of errors size 38 (66% severe) position errors on 35 (43%

severe) and orientation errors of 25 (44% severe). The size errors were more frequent and also, more often severe.

It was further observed that the errors were not always isolated. One component part could accommodate several and different types of error simultaneously, resulting in more complex form lesions in two of the formal properties, or even in all three. For 49 isolated errors we found 146 multiple errors, 98 of those being doubles and the remaining 48, triples. Therefore, the most common cases were double errors appearing in the same drawn figure part. Moreover, the percentage of multiple serious errors was 84%, a value that dropped to 66% when errors were partial.

We also found three types of possible error pairs in the following quantities: orientation/relative position - 11, size/orientation – 14 and size/relative position - 23. It was found that the pair size/relative position was the most prevalent, affecting forms 49% times. These pairs of errors suggested that drawers were not given due attention, as a result of only concentrating in one formal aspect, the one that showed to be controlled in the end.

Thus, the error pair most common (size / position) may have resulted from the drawers' highly directed concentration on orientation, a form property which may have determined all other drawing implementation. Possibly the rule used was: "Exactly reproduce the line, or stroke, orientation in the model and through their intersections you will find sizes and directions (relative position)." The pair size/orientation suggested that the drawer was focused on the relative position, not giving due attention to two other properties of the shape. Apparently, then, the rule followed was: "Exactly reproduce the model form connection points (relative position) since the size and orientation of the form will result from connecting them." The pair orientation/relative position suggested that the drawer was attempting to build the drawing focusing on the sizes, and ready to sacrifice position and relative orientation. The unwritten rule seemed to be: "Reproduce the exact sizes in the model form (following some orientation) they will result in connections (relative position)." For such a hypothesis to be plausible, it is expected that the same pair of errors was recurrent for that drawer during the entire drawing performance.



Participant:	4				
Drawing:	3				
	SIZE	ORIENTATION	Rel. POSITION	CONFIGURATION	TOTAL
Head	0,125	0,25	0,25	0,25	0,875
neck	0	0,25	0,25	0	0,5
ears, nose, eyes, mouth	0	0	0	0	0
chest	0	0,25	0,25	0,25	0,75
basin	0,25	0,25	0,25	0,25	1
arm1	0,25	0,25	0,25	0,25	1
forearm1	0,25	0,25	0,25	0,25	1
hand1	0,25	0,25	0,25	0,25	1
arm2	0	0,25	0,25	0	0,5
forearm2	0,25	0,125	0	0	0,375
hand2	0,25	0,25	0,25	0,25	0,875
thigh1	0,25	0,25	0,25	0,25	1
leg1	0,25	0,25	0,25	0,25	1
foot1	0,25	0,25	0,25	0,25	0,875
thigh2	0,25	0,25	0,25	0,25	1
leg2	0,25	0,25	0,25	0,25	0,875
foot2	0,125	0,25	0,25	0,25	0,875
Totals	3	3,875	3,75	2,875	**13,5**
Efficacy percentage					**84%**

ILLUSTRATION 6. REPRESENTATIONAL EFFICACY ANALYSIS FROM EXPERIMENT 3

Participant:	8				
Drawing:	4				
	SIZE	ORIENTATION	Rel. POSITION	CONFIGURATION	TOTALS
Backrest	0,25	0,25	0,125	0,25	0,875
backrest support 1	0,25	0,125	0,125	0,25	0,75
backrest support 2	0,25	0,25	0,125	0,25	0,875
seat- side 1	0,25	0,25	0,25	0,25	1
seat- side 2	0,25	0,25	0,25	0,25	1
seat cushion	0,25	0,25	0,25	0,25	1
arm 1	0,25	0,25	0,25	0,25	1
arm 2	0,125	0,125	0,25	0,125	0,625
arm support 1	0,25	0,25	0,25	0,25	1
arm support 2	0,25	0,25	0,25	0,25	1
metal piece	0,25	0,25	0,125	0,25	0,875
column	0,25	0,25	0,25	0,25	1
leg1	0,25	0,125	0,25	0,25	0,875
leg2	0,25	0,25	0,25	0,25	1
leg3	0,125	0	0,25	0,125	0,5
leg4	0,125	0,25	0,25	0,25	0,875
Totals	3,625	3,375	3,5	3,75	**14,2**
Efficacy percentage					**89%**

ILLUSTRATION 7. REPRESENTATIONAL EFFICACY ANALYSIS FROM EXPERIMENT 4

The analyzed data, pairs of errors in each participant's chair drawing, confirmed this assumption, sustaining the possibility that untrained drawers focus mainly on one form property and accommodate formal errors in the others.

Two participants had exclusively the same pair of errors. In the others, more than two types of error pairs did not arise in any case, and there was always a very clear predominance of a particular pair - except for one case in which two pairs shared 50% of the cases, this being the referred to case of the exceptional drawer who reached the highest degree of representational efficacy.

DISCUSSION

The process designed and tested here showed it was possible to disassemble shape in several specific aspects that objectively influenced the final representational efficacy during the drawing constructive process. The process has proven able to address the holistic complexity of the drawing's represented shape and simultaneously to be quite specific in its local inquiry, distinguishing different kinds of formal inaccuracies.

This model for accessing representational efficacy allowed us to: a) objectively distinguish which parts of the drawing were in conformity with the model form and which were not; b) specify the formal aspects that were poorly developed penalising each drawing representation, and to what extent; c) provide a quantification of the drawing representational efficacy level; and also d) provide interesting clues about error dynamics during the task.

All the data achieved are important to observational drawing teaching not only because it specifies the aspects upon which the formal representational efficacy depends, but also because it informs which aspects exhibit more difficulties to the draughtsman, and so still need improvement. The reliability of the process design needs more testing, namely a comparison of results with a qualitative evaluation on ordinal scales by multiple critics on the same form issues.

The method also provided groundbreaking insights about drawing error dynamics that deserve further research. As this study suggests, awareness of error dynamics can be very helpful in informing observational drawing teaching, particularly concerning the means of controlling human attention mechanisms that go on during the drawing process, and specifically focusing attention on the various model shape properties as examined here.

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Special Edition:
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LEARNING TO PERCEIVE: INFORMING PEDAGOGIC PRACTICE THROUGH THE EMPIRICAL STUDY OF DRAWING

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INTRODUCTION

This paper is the result of collaboration between psychologists with an interest in the cognitive processes underpinning drawing activity (Chamberlain, McManus and Brunswick), a dyslexia support tutor (Rankin) and an art school lecturer in drawing (Riley). It reports on a small-scale, 'pilot' workshop, designed to test the pedagogical strategies specifically designed for dyslexic students, with a cohort of volunteers from across the Royal College of Art, London. The workshop consisted of drawing activities specifically designed for dyslexic/dyspraxic students, carried out over a period of three days at the RCA, July 2012. The call for volunteers specified participants who felt their drawing skills to be inadequate, and who had been recently identified as dyslexic or dyspraxic. Five respondents who fitted the criteria formed the full sample of workshop participants.

Our literature search revealed no alternative methods for garnering data about the efficacy of teaching drawing to dyslexic/dyspraxic art and design students, and so this experiment offers an original contribution to the field of drawing pedagogy.

Mastery of observational drawing appears to be of importance to both art students and practitioners by enhancing perceptual processing regardless of an artist's specialist medium (Kozbelt, 2001; Seeley & Kozbelt, 2008). In a recent study, 64% of a cohort of 82 art students stated that improving their observational drawing skills whilst they were at art school was very important to them (Chamberlain, 2012). This improvement may be achieved through the use of evidence-based teaching strategies which develop from an increased understanding of the perceptual processes underlying drawing ability. With that in mind, the current study assessed the contribution of figure-ground dependency and perception of simple angular and proportional relationships in relation to drawing accuracy.

It was found that a bias toward enhanced figure-ground independency and toward accurate perception of angles and proportions in a non-drawing context both contributed to drawing ability, and also related to one another (Chamberlain, McManus, Riley, Rankin & Brunswick, 2012). However, some researchers (e.g. Lawton, 2011; Livingstone, Rosen, Drislane, & Galaburda, 1991) have argued that difficulties with figure-ground discrimination and pattern analysis represent a core deficit in dyslexia resulting from faulty timing of cells within the visual system. The spatial and temporal sequencing problems caused by this faulty timing impact on both the individual's reading and drawing ability.

In order to elucidate the causal relationship between perceptual abilities and drawing ability in dyslexic students, it was necessary to explore whether the implementation of a structured teaching programme focused upon these faculties would improve drawing ability. It is argued that greater figure-ground independency can be established by teaching techniques that encourage the awareness of concepts such as negative spaces and contrast boundaries, and that the judgement of simple angular and proportional relations can be improved by relating salient points of the primary geometry (the relationships between edges, corners and surfaces in the perceived world) of the subject-matter to the secondary geometry (the relationships between points, lines and tones on a drawing's surface) of the drawing itself. A qualitative pilot study was conducted within a series of drawing workshops at the RCA, utilising teaching strategies pertaining to these perceptual faculties, to assess the potential impact on perceptual processing and drawing ability. Results from both the quantitative and qualitative studies were presented in the form of a video at the *Thinking Through Drawing* conference, Wimbledon, 2012 with a view to marrying up practical teaching strategies with the growing body of psychological evidence for perceptual enhancement in drawing.

AN EIGHT-STEP STRATEGY FOR TEACHING DRAWING

The body of this paper is a transcript of the video made over the three days of drawing workshops.

The video begins with a proposal for a strategy for teaching drawing:

1. To focus attention upon the subject matter and the relationship with the surroundings (figure/field relations). This entails making decisions about format: portrait or landscape.
2. To construct a general structure, or scaffolding, in terms of relating the main axes of the drawing paper to the main axes of the subject-matter, using, for example in life-drawing, the 'invisible N-grid' of lines running across the figure that connect salient points such as Nose, Nipples, Navel, kNees, and kNuckles. These axes might be the means by which students hone their skills of accuracy in drawing angles and lengths in proportion so that the repetitive, low-level exercise is perceived to have contextual meaning for the student.

3. To introduce visual concepts such as ‘contrast boundary’ in place of the common term ‘outline’. This immediately engages the student with the variety to tonal values across the whole subject matter and, in particular, allows the student to notice how the contrast boundary fluctuates at the edges between figure and field. The concept of ‘negative space’ (spaces between those items in the visual field normally labelled with language), can also aid students to look without language, to apply specifically non-verbal methods in the process of drawing.
4. To repeat these first three steps at the beginning of every new drawing.
5. To discuss with the tutor the process under way on the drawing board.
6. To repeat the instructor’s strategy with support from the tutor.
7. To draw independently at unsupervised open-access sessions.
8. To re-demonstrate the practices and strategies offered by the tutor in order to reinforce them.

The eight-step structure is based upon research by Nist and Mealey (1991) into strategies for teaching dyslexic students, strategies which have not been applied in the teaching of drawing before, but which make use of insights well known to teachers of drawing; for example, those applied by Betty Edwards in her well-known book *Drawing on the Right Side of the Brain* (1979), updated in 2012.

What follows is an edited transcript of the interviews conducted before and after the drawing exercises. Five students were interviewed, each from a different department of the RCA. All participating students were studying at post-graduate level, all have spent a minimum of four years at art school prior to enrolling at the RCA, and all are either dyslexic or dyspraxic. In order to protect the students’ identities their names are not included; however each student is described by their studio practice.

TRANSCRIPT OF INTERVIEWS

Fashion student interviewed before workshops:

> *My drawing is a bit insecure it’s not as beautiful as it is in my head I struggle with knowing how to get the proportions right on the sheet of paper.*

Fashion student interviewed after the workshops:

I think what we have been talking about contrasts and spaces and just paying attention to other things rather than stressing about how to get the object on the paper has really helped. So you start approaching it from a different position you start approaching it from behind in a way. You focus on different things and by focusing on different things the object appears more effortlessly on the paper and if you just follow the guidelines then it appears to look right. This approach adds some more playfulness and relaxes the hand as well. So the hand is not so cramped you get some movement and playfulness and that's what brings the drawings alive.

Ceramics student before:

I think drawing for me is a lot to do with fear. I tend to go over lines to make sure they are right then I rub out and re-draw. It's not as free flowing as I wish it to be. Just to get ideas on paper and then move forward is an issue for me.

Ceramics student after:

The issue of space and primary and secondary geometry and all of the different things that Howard has been mentioning I naturally wouldn't be inclined to think about. Before I'd just get lucky with proportion and if not, I just kind of try and compensate somehow but now I'm adjusting myself and planning out before hand. Having a bit of structure helps me focus and gives me a system to use. In terms of proportion I should have made the first picture as a portrait and I can see that now instead of squishing it all in. I also went straight into surface detail rather than getting all the basic shapes into the scene and I feel like now I'm aware of the negative spaces that you mentioned and also of how things relate to each other. Another thing I would never have considered before is trying to create a horizon and relating the objects to that. I always used to leave things isolated, floating in space.

Product design student before:

I can't control the shape of the object and also I don't know how to control the connections of how the shapes relate to each other, and also I'm not good on construction.

Product design student after:

First of all I got more confidence. I learnt a lot to think about the relationships between objects; also I'm thinking more about the marks I'm making in space which I never thought about before.

Design Engineering student before:

I generally try to avoid it. I imagine my idea and then work quite a lot in 3D so I go straight from my head into making and really skip the whole drawing bit. My sketchbook doesn't have any sketches in it, it's full of schematic drawings it's nice to see how things evolve through drawing because I don't really get that. I think sometimes that doesn't come across very well to my tutors the fact that I have been designing and refining my idea quite a lot, because there isn't really anything for them to see. Also it's tricky if you're working for clients they can't see how stuff is moving on and changing because it doesn't come out vey well when I try and draw it. I tend to draw things in a more technical drawing style.

Design Engineering student after:

I'm just far more confident now and I seem to have better co-ordination between looking and drawing, from moving from what I see onto the page. It feels more fluid.

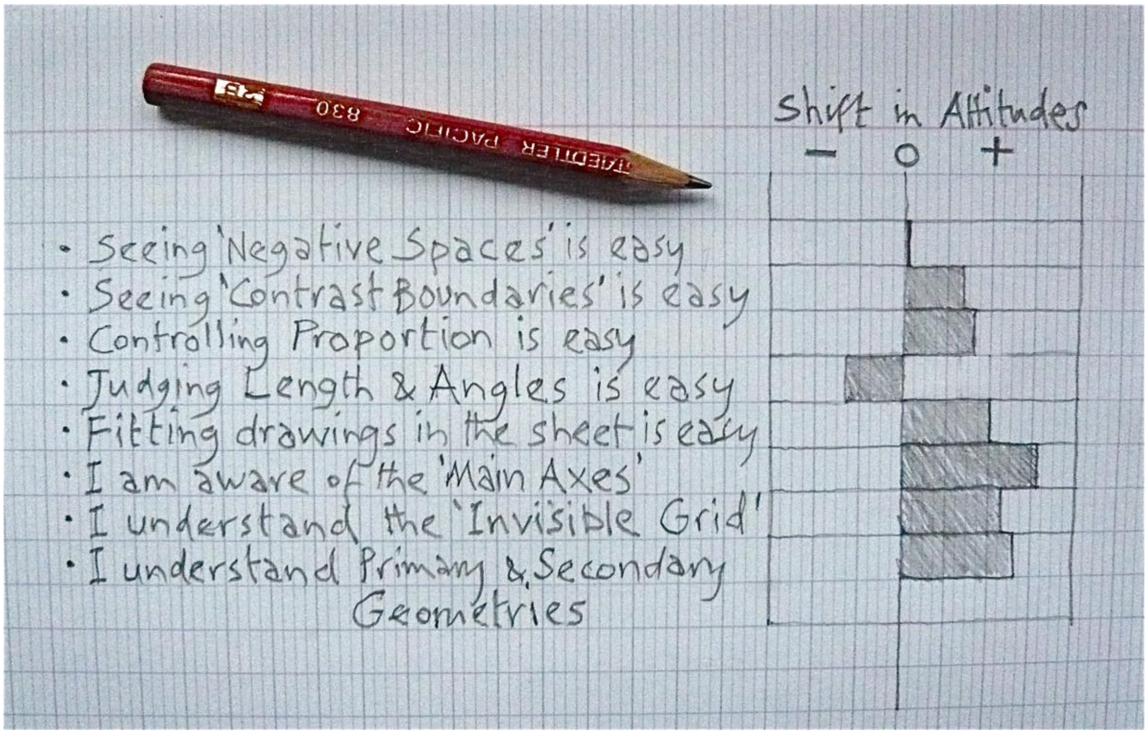
Vehicle design student before:

It's drawing my ideas that I really struggle with. If I'm drawing an object I can generally get a reasonable accuracy with the shape but it's when I'm trying to draw an idea I'm too focused on the design of it instead of sketching the whole thing, so the proportion and scale are wrong because I can't replicate what I'm thinking.

Vehicle design student after:

It's helped me to quantify a process whereas before because I didn't understand what I was doing and my drawing could be very erratic. Often I feel I rush my drawings and don't really consider proportion, which is a big issue that I have.

SUMMING UP BY HOWARD RILEY, DRAWING TUTOR:



Questionnaires probing students' attitudes towards technical aspects of drawing ability were completed before and after the workshops. Although the group was small some useful indications emerged which will inform future research plans. For example all students recognised the high value of perceiving negative spaces even before the workshops, hence little change in their attitude towards that aspect of tuition. Shifts in attitudes towards other technical aspects introduced, such as the concept of contrast boundaries, the awareness of the main axes, their relation to format choices and, the relationship between primary geometry (relations between edges and surfaces in 3-D space) and secondary geometry (relations between points, lines and shapes on the 2-D drawing surface), were all strongly positive.

One intriguing outcome was the apparent contradiction between the group's positive shift in attitude towards the ease of controlling proportion as opposed to the negative attitudinal shift concerning their ability to judge lengths and angles. Heightened awareness of the crucial importance of judging length and angle may well have increased their cautiousness in responding positively to this aspect of the tuition.

Finally we're pleased to report that every student involved considered their drawing ability had been improved by participation in the workshops.

DISCUSSION

The main themes emerging from these interviews reflect the importance of providing a framework to focus the students' drawing, and to help them to see how the edges and surfaces of objects fit together in space. Having this clear structure then gives students confidence in the drawing process, essentially the transformation of primary geometry into points, lines, shapes, tones and textures of the drawing itself, which helps them to relax so that their drawing becomes more fluid and effortless. (The complexities of colour were omitted from these exercises.) On the basis of the majority of categories of drawing abilities, students saw an improvement. Although students appeared to perceive the judging of angles and lengths to be harder after the drawing course, we can suggest that this is a result of their enhanced appreciation of the task of breaking down the visual scene and to accurately depict the subcomponents. The course has provided them with the tools to achieve this, although undoubtedly their improvement in the future will be very much dependent on their willingness to engage with these tools during their drawing practice. The group dynamic throughout the workshops was a very positive and mutually-supportive one, which encouraged each participant to experiment with the visual strategies introduced.

Future work by our research group will explore in greater depth the relationship between specific skills that are key to mastery of observational drawing ability in dyslexic and dyspraxic art students. Additionally, we will further refine our evidence-based teaching strategy to help such students learn these skills in small, tailor-made workshops with the intention of improving their drawing ability whilst at art school.

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TOWARDS SUPPORTING INTERACTIVE SKETCH-BASED VISUALISATIONS

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The goal of the information visualisation community is to develop interactive visualisations of abstract data to aid in cognition. While most information visualisation research approaches this from a data-driven or a task-driven perspective, our objective is to gain a better understanding of how people already use visuals in their everyday thinking processes and to apply this understanding to create new information visualisations. To this end, we have performed three observational studies: one, looking at the lifecycles of sketches and diagrams used by software developers, another looking at the visual constructs on knowledge workers' whiteboards, and a third examining how people might interact with a pen-and-touch based system for data exploration using charts. In this paper we group the findings of these three studies to develop a fuller picture of the ways in which people use sketching for visualisation tasks.

INTRODUCTION

Information visualisations are interactive, computer-supported visual representations of abstract data, that is, data with no inherent spatial mapping. Card et al.'s oft-cited definition maintains that the goal of information visualisation is to *amplify cognition* by creating interactive visualizations of abstract data (Card, Mackinlay and Shneiderman, 1999). In other words, information visualisations are created to help people think about their data: to find patterns, interpret relationships, explore possibilities, and perhaps most importantly, gain new insights based on the data.

This goal is strongly aligned with the purposes for which people create their own ad-hoc, external visuals, such as sketches, in their everyday thinking processes. People create, re-create, and manipulate their own external visual representations of concepts, ideas, and processes to "extract meaning, draw conclusions, and deepen our understanding of representations and the world more generally" (Kirsh, 2010: 453). That is, people create visuals to enhance their own cognition about the information or concepts they encounter.

The idea of approaching information visualisation from the perspective of visual thinking processes (due to the similarities in the underlying motivation for both) is underexplored; the common approach to creating information visualisations is driven by the underlying data or the tasks to be performed with the visualisations. Our objective is to gain a better understanding of the use of visuals in everyday thinking processes and to apply this broadened understanding to create new information visualisations. Ultimately, such an approach could be useful for creating information visualisations that better integrate into everyday visual thinking processes and through this are able to better support the goal of insight generation.

We have conducted three preliminary studies related to observing everyday visual thinking processes for the purposes of information visualisation creation: two observational studies of software developers and knowledge workers, and one study of an initial sketch-based data exploration prototype. In this paper, we synthesise the results of the three studies and comment on the broader themes and implications that emerge from the results.

BACKGROUND

The term *visualization* can have many meanings, but we restrict our usage of the term to conform to the definition given by Card, Mackinlay and Shneiderman (1999: 6):

> *"The use of computer-supported, interactive, visual representations of data to amplify cognition."*

The goal of such visualisations is to support thinking about the underlying data. This results in visual representations that are dependent upon the structure and content of the data and that also have some degree of interactivity, that is, the potential to be manipulated in order to display different views of the data. It takes considerable up-front work to create a visualisation, so often the person who uses the visualisation – the data analyst, the knowledge worker, the magazine reader – is not the one who creates it.

The term *information visualisation* (InfoVis) refers to a subset of visualisations that represent primarily abstract data (Card, Mackinlay and Shneiderman, 1999). Abstract data is data that does not have an inherent spatial mapping, for instance, textual or financial data (an example of data with an inherent spatial mapping would be geographic data). This means that the creator of an information visualisation often has significant freedom with respect to how to spatially arrange the data in the visualisation. Heer, Bostock and Ogievetsky (2010) have explained a number of popular techniques for visualising common types of data in information visualisation: time-series data, statistical distributions, maps, hierarchies, and networks.

In contrast to these computer-supported visualisations there are *external visual representations*: ad-hoc, usually analog visual representations of thought, concepts, or data, created to aid in cognition. Examples of such visual representations include sketches jotted on an office whiteboard, mind maps, diagrams of software architecture, or sketches of a software interface. These representations are often casual, not tied to data, and are *static*, that is, they have no capacity for interactivity: to change their view, one must create a new representation or modify the current one by erasing or drawing over it.

Approaches to Information Visualisation Design and Evaluation

To date, the most prominent approaches to creating information visualisations have been from data-centric and task-centric perspectives. Earlier work was largely data-centric, characterised by a focus on how to represent various data type structures. As noted by Amar and Stasko (2004), this perspective is characterised by the belief that “good data speak for themselves”. The cartographer Jacques Bertin (2011) laid out many of the early foundations for data representation, among them a system of atomic ways in which a mark on a page can vary, called visual variables (these are the *x* dimension, the *y* dimension, size, value, texture, colour, orientation, and shape). Edward Tufte's ideas about data display, such as minimising data ink, integrity in graphics, and the mantra to “above all else show the data" (Tufte, 1983) were also quite influential here, as were studies about the limits of human graphical perception (Cleveland and McGill, 1984). This perspective has led to new representations of data structures such as multi-dimensional scattergraphs and tables, node-and-link diagrams, and trees (Card and Mackinlay, 1997).

The task-centric approach to information visualisation goes beyond focusing solely on the way data is represented and calls for consideration of the tasks that will be performed with the data. Several researchers in the information visualisation community have argued that it is important for visualisations to bridge the gap between the data representation and the higher-level, analytic task to be performed with the data (Amar and Stasko, 2005), and to be useful in real-world application domains (Plaisant, 2004).

More recently, some researchers have explored a wider range of aspects related to information visualisation, reflecting on the role of interaction in a visualisation as well as on the broader purpose of InfoVis. North (2006) points out that this "broader purpose of information visualisation" is to generate insights. However, he notes, insight is an elusive concept to define and evaluate, which could explain why so many visualisations are still evaluated for how efficiently and accurately they enable one to perform low-level interpretation (as opposed to analysis) tasks. He proposes that a move away from controlled benchmark evaluations to more complex benchmark evaluations, or even open-ended, qualitative evaluations is necessary for a greater understanding of the relationship between visualisations and insight. A similar perspective motivates our work.

The Use of Visuals in Thinking Processes

External cognition, as explained by Card, Mackinlay, and Shneiderman (1999), encompasses any use of the external world to accomplish cognition. One such type of external cognition is visualisation, including information visualisation; another is *externalisation*. Kirsh (2010) defines externalisation as the reification of an internal object of thought, and identifies several reasons why externalisation might occur:

- To help to offload memory (the most commonly cited purpose of externalisation);
- To enable the solution of problems that are beyond the mind's capacity to simulate; and, above all,
- To optimise the cost of completing a task. That is, externalisations can allow tasks to be completed more efficiently, more fully, and in collaboration with others (an externalisation is a concrete, visible, so it can be shared or modified by multiple people).

One commonly used type of externalisation is sketching. Research into sketching practises is particularly prevalent in fields whose practitioners rely on sketches of physical objects, as in design (Buxton, 2007; Schütze, Sachse and Römer, 2003), architecture (Goldschmidt, 2003), or engineering (Ferguson, 1994). A key finding in this body of research revolves around the importance of the ambiguity inherent in sketches. Sketches may contain rough lines or empty spaces where ideas or details have not been finalised. Seeing these rough, unfinished lines in the context of the sketch can spark new ideas. Tversky, et al. (2003) explain this as a process whereby we re-perceive or reinterpret the ambiguous parts of a sketch to create a new idea; they call this *constructive perception*, and state that this skill can be fostered and applied to various domains. Goldschmidt (2003) calls this process the "backtalk" of sketches, wherein one begins a dialogue by drawing a sketch, and the sketch "talks back" by being a catalyst for ideas.

While sketching is popular in the physical domains described above, knowledge workers working with more abstract concepts often create ad-hoc “thinking” sketches. Whiteboards are a particularly fitting environment for the creation of such sketches. Tang, et al. (2009) and Andrews, Endert and North (2010) have noted that the flexible nature of whiteboards allows for assigning varied meanings to freeform representations. In a study of office workers' whiteboards, Mynatt (1999: 6) found that the whiteboards were used for thinking, noting:

> *“All manner of incomplete and seemingly vague content was written as participants used their whiteboard as a scratch surface while pondering concepts much larger than their surface representations”*

The three studies we synthesise here have focused on the practices used, visuals created, and tasks performed by knowledge workers.

Information Visualisations Inspired by Human Behaviour

In contrast to the conventional data- and task-centric approaches to information visualisation creation outlined earlier, some researchers have begun to use observations of people’s behaviour with visuals and visualisations to inspire new information visualisations. Van Ham and Rogowitz (2008) asked people to arrange and construct visualisations of graphs to inform automatic graph layout algorithms. Dwyer, et al. (2009) compared human-generated graph layouts against automatic ones and found that the human-generated layouts performed as well as or better than the automatic layouts. Still others have been inspired by people’s sketching behaviour in general. NapkinVis (Chao, Munzner and van de Panne, 2010) is a sketch-based tool for creating simple visualisations inspired by the common idea of sketching on the back of a napkin. SketchVis (Browne, et al., 2011) is a pen-based whiteboard system for creating bar and line charts and scatterplots; it was a precursor to the SketchInsight system that is a part of the synthesis in this paper (Walny, et al., 2012).

Kessell and Tversky (2011) have outlined a similar approach for designing static visualisations, which they call the Production-Preference-Performance program. The three phases of this program can be summarised as follows:

- In the *production* phase, people are asked to create visualisations of the information, which reveals how people understand the structure of this information.
- In the *preference* phase, people are shown several alternative visualisations and asked which is the best representation of the information.
- In the *performance* phase, people are asked to perform tasks on one of several visualisations, which reveals how well they are able to interpret the information in the visualisations.

Tversky, et al. (2007) used this model on inherently spatial information – route maps and furniture assembly diagrams – to determine a set of cognitive design principles that could be applied in automatic generation of such visualisations. The program was also applied to information of a more abstract nature, such as tracking objects across space and time (Kessell and Tversky, 2011), and representing abstract categorical and continuous information in a network diagram (Tversky, et al., 2012).

The three studies outlined in this paper follow a similar "human-driven" philosophy: we observe the visual representations people make, their interactions with visuals, and the environment and contexts surrounding the use of the visuals. We analyse the study data in light of our goal of informing new information visualisations that support everyday thinking processes.

THREE STUDIES: A BACKGROUND

What follows is a brief explanation of the three previously-published studies whose results we have synthesised below.

Studying lifecycles of diagrams and sketches (Sketch Lifecycles)

The first study, which we will refer to in the synthesis as the *Sketch Lifecycles* study, centered around collecting the lifecycles of diagrams and sketches that were important to individual software developers. Sketching is a popular practice in software development, both in programming and in prototyping. Cherubini, et al. (2007) found that software developers often use temporary sketches and diagrams and that some of these sketches are revisited or redrawn multiple times over the course of a project, slowly evolving each time. This finding inspired our study, in which we studied why and how such sketches are revisited.

We asked eight researchers who develop software to choose a recent software development project and, in a semi-structured interview, tell us about a sketch or set of sketches that was important to them throughout that project. We performed a qualitative analysis of the interview transcripts using an open-coding approach. This resulted in a characterisation of the lifecycles that sketches important to researcher/software developers undergo, transitioning between both media and contexts of use. We visualised ten lifecycles from eight participants as lifecycle diagrams (see Figure 1 for an example).

Participants were characterised according to whether they (a) sketched frequently and were highly invested in their sketching workflow; (b) sketched frequently but had an ad-hoc sketching workflow; and (c) sketched infrequently. We found five types of transitions: (1) *creation* (the externalisation of an idea into a sketch or diagram); (2) *iteration* (the modification or re-creation of a sketch or diagram); (3) *copying* (making a direct reproduction of a diagram); (4) *archival* (when a sketch or diagram is no longer actively used); and (5) *discarding* (when a sketch or diagram is discarded, usually deliberately).

This study made it apparent that people are very particular about the way they interact with their sketches and diagrams, whether these are analog or digital. Each lifecycle was unique, even when we collected multiple lifecycles from the same participants. The full results, including all of the lifecycle diagrams and characterisations of the participants, can be found in the proceedings of the 2011 IEEE International Workshop on *Visualizing Software for Understanding and Analysis* (Walny, et al., 2011a).

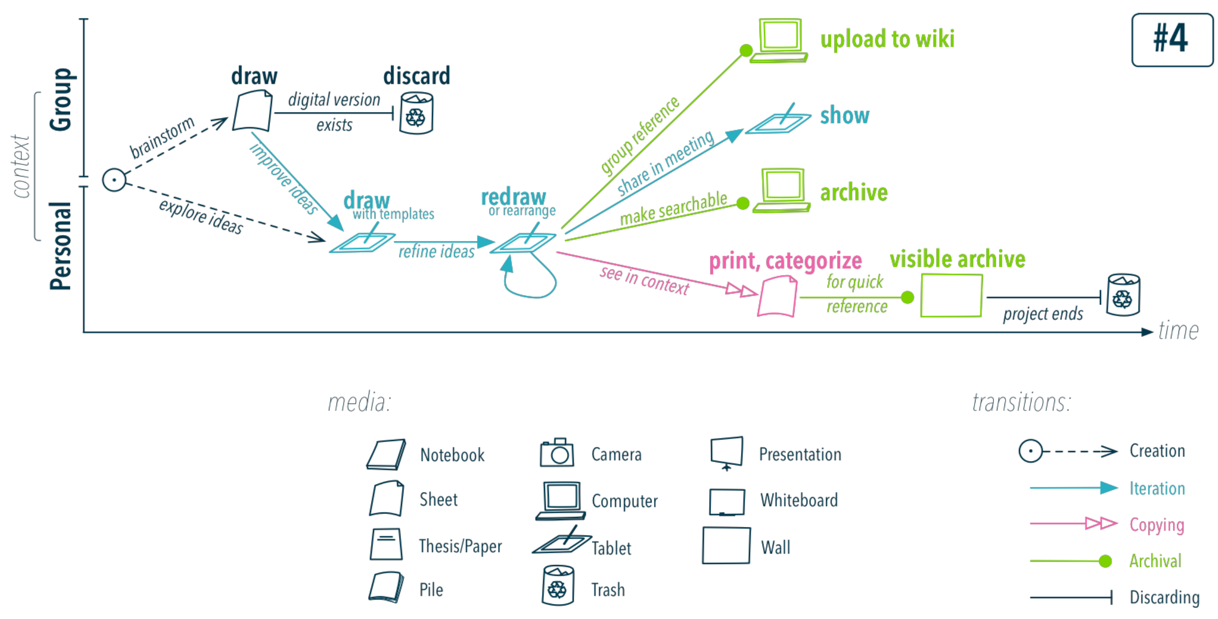

FIGURE 1: A LIFECYCLE VISUALISATION FROM OUR SKETCH LIFECYCLES STUDY SHOWING THE TYPICAL LIFECYCLE OF SKETCHES DRAWN BY PARTICIPANT 4. THE LEGEND SHOWS THE BREADTH OF MEDIA AND TRANSITIONS WE CATEGORISED. *FIGURE ADAPTED FROM A PREVIOUSLY PUBLISHED FIGURE (WALNY, ET AL., 2011A).*

Studying visual constructs on whiteboards (Visual Constructs)

Our second study (referred to as the *Visual Constructs* study in the synthesis) focused on snapshots in time of knowledge workers' sketches on whiteboards. We performed a qualitative study in which we collected, unannounced, 82 photographs of whiteboards from 69 knowledge workers' offices at a large research institution and analysed them from two perspectives: (1) the types visual constructs used and (2) the relationship of words to diagrammatic constructs. In our analysis of visual constructs, we looked at: recognisable information visualisation constructs (such as timelines, trees, node-link diagrams, and data charts); spatial organisation factors (such as density of coverage on the whiteboard and methods of separation and grouping); layering (palimpsests and erasing); and communicative factors (including emphasis, negation, use of ellipses, and "sketchiness" of lines drawn). In our analysis of the relationship of words to diagrammatic constructs, we extracted a *words-to-diagrams spectrum* (see Figure 2) that showed the various ways in which we saw words and diagrammatic constructs coexisting on the snapshots.

FIGURE 2: THE WORDS-TO-DIAGRAMS SPECTRUM, WITH REPRESENTATIVE EXAMPLES. *FIGURE ADAPTED FROM A PREVIOUSLY PUBLISHED FIGURE (WALNY, ET AL., 2011B).*

We also interviewed ten participants of the study to validate our interpretation of the whiteboard constructs and to gain a deeper sense of the participants' whiteboard usage. We found a myriad of interesting characteristics, including some that are at odds with current information visualisation guidelines, such as a large tolerance for clutter and a tendency to view words as primary objects rather than as labels. The full results of this work are available in the IEEE Transactions on Visualisation and Computer Graphics (Walny, et al., 2011b).

Understanding pen and touch interaction for chart creation and manipulation on interactive whiteboards (SketchInsight)

Reflecting on the results of the previous two studies, we found that creating information visualisations based on our understanding of visual thinking will likely necessitate stepping away from conventional computer interfaces that involve windows, icons, menus, and pointers (known as WIMP interfaces) and exploring "post-WIMP" interfaces. These post-WIMP interfaces often involve new hardware combinations, for example pen and multi-touch input devices, for which there exist many untested interface design possibilities.

As a preliminary exploration towards designing such interfaces for information visualisations, we ran a study on a prototype chart creation and exploration system for pen and touch whiteboards, called SketchInsight (see Figure 3). We will refer to this in the synthesis as the *SketchInsight* study.

The central question of this study was: *how would people approach interactively sketching information visualisations?* We wanted to know what kinds of pen and touch gestures people would gravitate towards when creating and modifying charts in SketchInsight. To answer this question, we designed the study as a *Wizard of Oz* study: that is, the system was not fully capable of recognising the pen and touch input. Instead, whenever participants interacted with the system by drawing a stroke on the screen or using some sort of multi-touch gesture on the screen, a hidden experimenter (the "Wizard") rapidly interpreted these interactions and instructed the system on how to respond. This setup allowed the participants to interact with the system however they desired, because the "Wizard", unlike a real software system, could easily interpret a wide variety of interactions in a logical way.

SketchInsight was designed to break away from the WIMP paradigm and follow several design principles intended to provide, to the extent possible, the benefits of using visual thinking tools such as whiteboards or pen and paper. These principles included: specifying what you want to see by drawing it ("what you draw is what you get"); supporting manipulation of objects that is as direct as possible; minimising explicit mode-switching (e.g. there was no need to switch between a "drawing" and a "moving" mode); and supporting flexibility with good default behaviours.

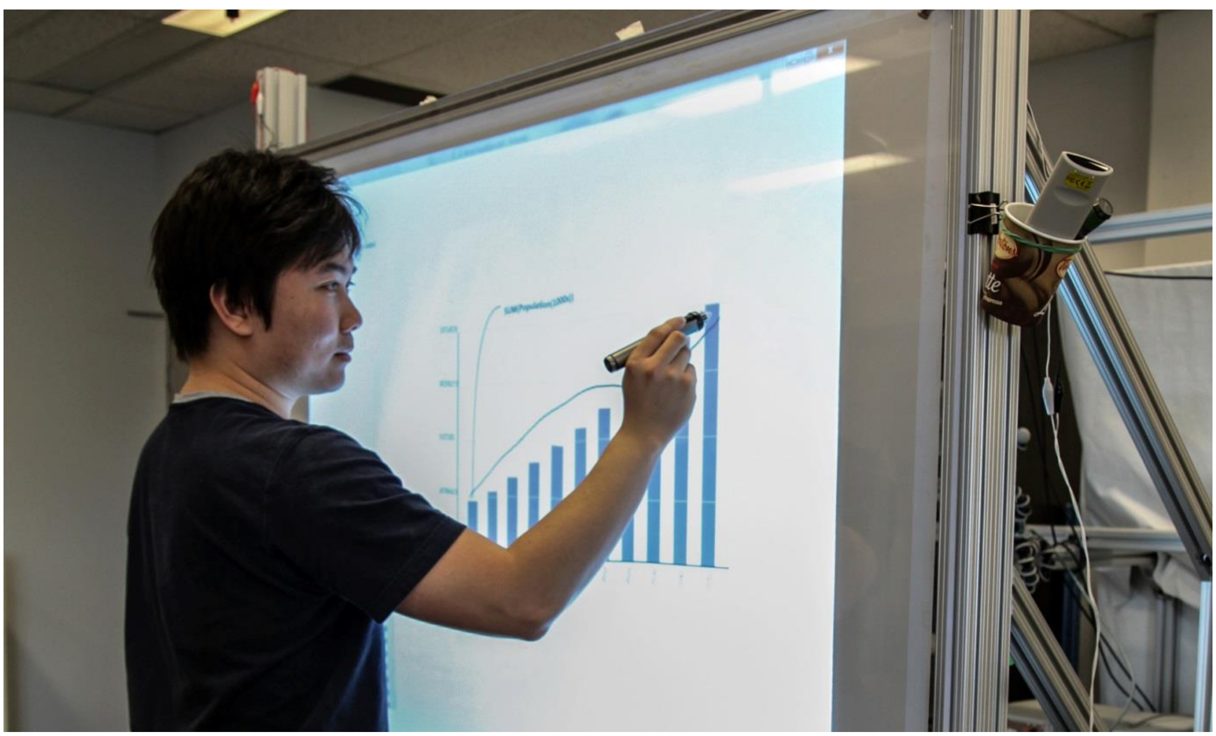

FIGURE 3: TURNING A BAR CHART INTO A LINE CHART USING THE SKETCHINSIGHT SYSTEM.

Highlights of our results include evidence that our participants readily used knowledge about both physical world interactions and knowledge they have already gained about the system to infer how to perform new tasks; indications that our participants had a clear idea of when to use pen interaction vs. when to use multi-touch gestures; and evidence that people tend towards integrated interactions, where interaction with the data and other elements on the screen occurs in proximity to the objects being acted on, rather than on far away menus, buttons, or other controls. The full results of the study can be found in the IEEE Transactions on Visualisation and Computer Graphics (Walny, et al., 2012).

SYNTHESIS OF RESULTS

We synthesised the results from the three studies, which we will refer to, respectively, as the *Sketch Lifecycles*, *Visual Constructs*, and *SketchInsight* studies. Our synthesis process was to chart the high-level results of each study, then search for the most prominent emerging themes, particularly those that were evident in the results of two or more studies at once. In a manner akin to affinity diagramming, we categorised individual results into their respective themes (a result could belong to more than one theme). Ultimately, our objective across all three studies is to help inform the design of new interfaces for information visualisation that further the information visualisation community's goal of supporting individuals' exploration and understanding of information. Thus, we have also reflected on the potential implications of our observations for creating information visualisations. In the following sections, we report on the individual themes and resulting implications.

Variations in Externalisation Characteristics

We designed the Sketch Lifecycles and Visual Constructs studies explicitly to allow us to observe externalisations, specifically sketches used to support everyday thinking processes. Consequently, we observed a number of characteristics related to externalisation that are rarely considered a factor in information visualisation creation. In particular, we saw a richness and variation in the way people externalise that contrasts strongly with the constraints seen in many visualisations, both in terms of the way visual constructs appear and in the support for various contexts of use.

In the Sketch Lifecycles study, we saw externalisation occur in the creation and iteration transitions. In the whiteboard study we saw only a snapshot in time of externalisations. Across both studies, the breadth of reasons that we saw for the creation of these sketches were:

- To brainstorm, think, or explore ideas.
- To solve problems, for example to help debug software.

- To plan or organise, for example for writing a paper, doing a project, or performing a literature review.
- As a communicative aid, particularly to explain concepts to others.
- To offload memory, as a record of ideas or useful information.

These reasons for externalisation were supported by a variety of processes, mediums, and constructs, and a diversity of people. Some of our participants were highly reflective about their processes. For example, participant 4 in the Sketch Lifecycles study (see Figure 1) was determined to find an optimal digital workflow for his sketching practices; one participant in the whiteboard study was cognisant that the sketches on his whiteboard were much more useful to him personally than the formalised digital versions he had distributed to his team. Others were less interested in their workflows, and simply followed whatever path worked for them.

One strong factor of variation related to the visual constructs we observed. We saw a wide range of spatial organisation strategies. Some of these strategies related to space constraints. For instance, we saw various separation and grouping strategies, such as separating lines or boxes, and a significant use of colour as a separator. Orientation and layering were often used to fit more information into a small space, but we also talked to people who noted that orientation and spacing had particular meaning to them. For instance, one participant in the Visual Constructs study talked of words "radiating" out of another word, indicating a hierarchy of sorts. He also mentioned that subtle spacing between two constructs indicated a missing element. This subtle spacing was lost in a formalised, digital version of the same diagram later re-created using diagramming software.

We observed variations in other characteristics of visual constructs as well. Some noted that different colours, layers, and distinct personal sketching "styles" helped them to differentiate between sketch authors (for shared sketches from group meetings) as well as to encode temporal information, such as the order in which sketches were drawn.

Social context influenced variation in participants' workflows, evident in both the sketch lifecycle and whiteboard studies. It had a particular effect on whether analog or digital media were chosen. In the Sketch Lifecycles study, the participant who deliberately set up an optimal digital-based workflow still felt uncomfortable using anything but paper in group or even public settings. Another participant preferred to annotate printed computer-generated graphs in meetings rather than using the digital copy; he later preferred to reference these annotated copies despite his ability to re-generate the original graphs quickly. In the Visual Constructs study, one interviewee explained that he often preferred to use the whiteboard in meetings because it was more forgiving; although a computer simulation would be more precise and still get his point across, it would take longer to set up and made him nervous about making mistakes. Still others seemed to value *immediacy* in group settings, simply wanting to get the "gist" of a chart or hurriedly write something to get a point across. Several participants across both studies took care to formalise sketches they were sharing with others, but placed value on the original hand-drawn versions for themselves. For practical reasons, the change in social context from personal to sharing with a group necessitated a change in the medium used; these changes ranged from processes as simple as taking a digital photo of the sketch to careful formalisation using diagramming software.

IMPLICATIONS. Our findings suggest that there is large individual variation in spatial organisation strategies, visual construct characteristics, and the contexts in which people use external visual representations. In some cases, the freeform ways in which the visuals are drawn and organised contains information of value for the creator of the sketch, a value that is lost when translated to a digital form using currently available software tools.

Designing any software interface inevitably introduces some constraints in terms of how people will be able to interact with it. It is an exercise in tradeoffs: freedom in one area may mean a reduction in computational power or freedom in another area. However, the considerable variability we have observed suggests that, for our goal of supporting individuals' exploration and understanding of information, it may be useful to explore interfaces that favor greater freedom in the spatial organisation of visual constructs and also to support easily switching social contexts.

Immediacy and Effort Optimisation

A prominent theme across all three studies was a tendency towards valuing immediacy of the medium and towards effort optimisation. We saw several instances in which people gave up many seemingly attractive options, such as colour choice, tidiness, the use of real data or underlying computational power in favor of quickly and easily representing their ideas, minimising interruption to the thought process.

One sign pointing to the importance of immediacy and effort optimisation was the set of reasons why people chose to choose their particular (usually analog) tools in the first place. In the Sketch Lifecycles study, analog tools were by far the most preferred in the creation and iteration stages, with digital tools being more used for archival, formalisation, or sharing reasons. Although there are many potential reasons behind tool choice, one participant (participant 1) explicitly stated that she used a sketchbook rather than her Tablet PC for the creation stage because she did not have to wait for it to start up. Immediacy was also very important in group settings. Participants in the Visual Constructs study stressed the importance of "getting the point across" as the reason for using the whiteboard over other mediums.

Another sign was in how the tools were used. In the Visual Constructs study we observed many lines with a "sketchy" quality, particularly with data charts, which were drawn mainly to show general trends rather than be faithful to the data. In some diagrams it was clearly evident that if they were part of a larger context, that context was only displayed insomuch as it was needed, a characteristic that aligns with Furnas' concept of "just-sufficient context" (Furnas, 1986).

Those who used digital tools optimised their workflow for speed and effort as well, possibly more so than for the analog tools. For instance, participant 4 from the Sketch Lifecycles study set up an elaborate set of templates so that when he was sketching ideas on his Tablet PC he already had commonly used constructs ready to arrange as needed. He also archived all of his sketches using an online service that had the capability to recognise written text in the sketches, so that he could easily retrieve them later using a keyword search. In contrast, several other participants who created diagrams digitally used the simplest tools at their disposal that they already knew how to use, such as standard slideshow presentation software that included basic drawing tools. When it came to saving or discarding diagrams, we saw that many people would only discard something when it became "clutter" and actively got in their way, for instance when a digital version of a paper sketch was saved. Digital versions tended to get saved implicitly because they did not get in the participants' way on a regular basis – they could be stored and forgotten.

The SketchInsight study participants also demonstrated a tendency towards immediacy and effort minimisation. For instance, participants drew axes to initialise creating a chart; for one participant we could clearly see these axes evolve throughout the session from two carefully drawn axes to a lazy "L" shape. Most participants did not write out complete words once they realised that the system included the capability to display autocomplete suggestions for partial written words. They tended to quickly figure out what kinds of interactions the system was capable of and stayed within those bounds rather than experimenting with different possibilities; they also fell back on familiar physical metaphors when deciding when to use pen and when to use touch. We also noticed a tendency towards integrated interactions. People tended to interact with objects very closely to where they were located, which is in contrast to the way many information visualisation interfaces look; they often have controls located away from the elements they are to control.

IMPLICATIONS. These findings suggest that information visualisations may more effectively support the thinking process if they strive to reduce the amount of thought interruption involved in using the tool, both when working with a tool and considering the potential switches of social context from personal, to sharing for feedback, to sharing in a formal setting.

Communicative Aids

Thanks to the collaborative nature of whiteboards and the necessity for collaboration in the software development lifecycle, we noted the importance and characteristics of communicating with visuals used during the thinking process.

We saw sketches used in group contexts in order to: brainstorm, think, explore and refine ideas, plan, explain concepts, share ideas to get feedback, annotate feedback, and share formally. Some sketches were archived for group reference, often by taking a digital photo and uploading to a wiki or other shared archive. In one case, this record was of a mutual agreement to be referenced later; in other cases it was simply a record of thoughts or ideas discussed. One interesting observation was some people's reluctance to use digital tools for creating or even modifying sketches in group contexts, whether it was a fear of rudeness (as for participant 4 in the Sketch Lifecycles study) or a fear of making mistakes (one participant in the Visual Constructs study).

The external visual representations we observed contained several visual constructs that were particularly suited towards communication: various forms of emphasis and negation, forms of ellipsis (used to denote missing elements), and sketchiness of lines. The use of emphasis was extensive. We saw the use of size, bolding, circling, colour, starring, pointing to with arrows, and underlining, all freeform. We also saw a fair amount of clutter, which is tied to the previously mentioned value placed on “getting the point across” to others. Forgiveness of mistakes was cited as a characteristic of whiteboards that was a useful communicative aid. In several cases, across both the Sketch Lifecycle and Visual Construct studies, we saw instances of formalisation, where a hand-drawn sketch would be re-created in digital form and then shared with a wider audience. However, there was a tendency to value the hand-drawn sketch more for later personal reference.

IMPLICATIONS. The visual thinking process is clearly not constrained to the personal domain – often, visual thinking artifacts are shared with others, whether it be during the creation stage or for discussion or feedback of existing artifacts. Sensitivity to differing needs in changing social contexts is important. Further study is needed to understand the differences between visual thinking in personal versus group contexts, but it is clear that certain characteristics are useful in both contexts, such as the freeform nature of the medium and supporting various forms of emphasis. There is also a suggestion that methods that support quicker and easier formalisation for sharing contexts could be useful.

Record, Reference, and Distillation

We saw several instances in which people preferred having a history of their thoughts, sometimes coupled with a tendency to distill a series of thoughts into a summary. On the whiteboards we studied, layering was a temporal indicator: newer thoughts were written over older thoughts, which were kept "just in case they were right". Some whiteboards were silted and messy due to the presence of semi-permanent information. In the Sketch

Lifecycles study, we saw digital archives, sketchbooks, and piles of paper in chronological order. In both the Sketch Lifecycles and Visual Constructs studies, we observed the occurrence of a "summary sketch", which was representative of the current state of thinking about something and was particularly valued (some participants even explicitly discarded older sketches that had led to the summary sketch because they weren't valued anymore once the summary sketch was complete). Some participants even suggested that the neatness of their summary sketches reflected more developed, organised thought.

IMPLICATIONS. It is not currently a common practice to save previous states of exploration in information visualisations. Our findings suggest that it could be useful to save particular states in chronological order, whether to recall and compare them later, or simply to as a reassuring feature. The ability to summarise the current state of understanding of a visualisation, for example through annotations, could also be important.

Abstract Concepts

All of our studies have observed people who work with largely abstract concepts or data, rather than physical entities as in design, architecture, or engineering. This is by design, since information visualisations also deal with abstract data. Accordingly, we saw high importance attached to words; often, they were not merely labels (as they often are treated in visualisations) but actual elements of the diagrams themselves, used in place of pictorial representation. In the Visual Constructs study, we extracted a words-to-diagrams spectrum summarising the various combinations of words and diagrammatic constructs that we saw (see Figure 2). One participant of the Visual Constructs study speculated that more developed thoughts can be better expressed in paragraphs, whereas diagrams make it easier to represent her thoughts because she can specify relationships using arrows and spatial organisation. In the Sketch Lifecycles study, several people placed a high value on annotations they had made (in words) on their sketches, particularly during feedback sessions. And in the SketchInsight study, several people turned to writing commands to the system in words when they could not think of other ways to interact with the system.

IMPLICATIONS. These observations suggest that it is important, particularly when working with abstract concepts, to be able to use words as a primary representation. It may also be effective, when exploring data, to be able to include words directly in a visual representation to summarise current thinking.

CONCLUSION

Coming from the perspective of improving information visualisations, we have synthesised the results of three observational studies that looked at the lifecycles of sketches and diagrams in software development, visual constructs as used on knowledge workers' whiteboards, and initial interactions with a prototype for exploring data on a pen- and touch-enabled digital whiteboard. Several themes have emerged regarding the external visual representations and the contexts and ways in which they are used:

- The large *variation* in the constructs people use in their externalisations, and the contexts in which they are performed.
- The importance of *immediacy* and *effort optimisation* of visual thinking tools, which play a role in people's choice of tools at a given moment.
- The prominence of the *communicative* context in relation to the usage of visual representations, and the various requirements for supporting this context.
- The importance placed on having a *history* of the thought process, and of being able to *summarise* one's current state of thought.
- The usefulness of *words* when dealing with abstract concepts with no obvious visual representation.

Creating information visualisations is a complex process that, to date, has been driven by the characteristics of the underlying data, the low-level tasks to be performed with that data, and human perceptual capabilities. Our synthesis of the three studies sheds light on additional aspects relating to the ways in which people already use external visual representations, which could be applied to create information visualisations that better integrate into everyday thinking processes.

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