Beyond the Swatch:

How can the Science of Materials be Represented by the Materials Themselves in a Materials Library?

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Abstract

This thesis investigates the potential of materials to represent their science within the context of a materials library. Materials scientists and engineers select materials using the concept of quantifiable physical properties and map materials accordingly. Within the arts communities, processes of materials selection often employ less quantifiable mechanisms, where cultural and sensory perceptions sit alongside more pragmatic technical requirements. The culture and science of materials are both expressed in the objects that surround us every day. Much of the content of materials libraries is a mixture of objects in the form of material products and samples. The work of this thesis introduces a theory of material-objects and an isomorphic methodology for material-object creation that explores the relationships between form, function and materiality. It does so in an attempt to re-evaluate the nature of the contents of materials libraries and endeavour to highlight the science of materials. The theory and method are tested in the making and use of four sets of experimental material-objects; cubes, tuning forks, bells and spoons. These four sets of isomorphic material-objects attempt to advance the paradigm of the materials swatch and push the boundaries of the genre to reveal the social, cultural, philosophical and scientific aspects of materials and their relationship to objects. Each material-object renders the micro structures and behaviours of materials as experiential macro properties. In doing so the social, sensual and performative agency of materials is presented. Material-objects are used in the staging of a series of events that constitute experiments with encounter. Instances of material encounter are vital for the exchange of materials knowledge and the revelation of properties. The results of the research into material-objects and encounter offer a novel way of approaching the creation and curation of a materials library, with particular attention given to the development of new forms of swatches.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

This thesis is an investigation into the potential of materials to represent the scientific understanding of materials within the context of a materials library. The basic themes of this thesis are the culture and science of materials as expressed and investigated through objects. The notion of a material-object is conceived and, through both their making and encounter, used in an attempt to explore the relationship between materials, form and functionality. The sets of objects are constituted as forms of swatches that endeavour to push the boundaries of the genre and reveal the social, cultural, philosophical and scientific aspects of materials.

As part of the work that surrounds the conception of this thesis, I have undertaken the construction of a materials library within the laboratory environment of The Division of Engineering at King's College London. The construction of this library is not itself the focus of this work but rather the apparatus with which investigation can proceed. Throughout the following document, reference will be made to multiple and singular materials libraries. Therefore, it is important to note that hence forth, when capitalised as follows 'Materials Library', this thesis is referring to the Materials Library at King's College.

By way of an overview, chapter two of this thesis offers a survey of the main materials libraries currently in existence, focusing attention on the collections and methodologies of commercial ventures, professional resources and institutional collections. The chapter also introduces literature and information sources that deal with materials for the scientific and artistic communities, demonstrating the nature of the relationships that practitioners within these fields have with materials.

The third chapter introduces a theory of objects as relevant to the work of materials libraries; reporting on pre-established theory, conceiving of the material-object and proposing the material-object continuum. The trope of the swatch is presented and the potential for the creation of new types of swatches is identified. The notion of encounter is also established in this chapter and a set of experiments proposed for the exploration of material-objects.

Chapter four introduces the broadly ethnographic methodologies that have been used throughout the work of this thesis to address the gathering of data on human responses to the material-objects in instances of encounter. Specific methods are then discussed in relation to each of the experiments with material-objects and encounters.

Five experimental chapters follow, that deal with the creation and use of isomorphic sets of material-objects within a materials library and the ability of the material-object to represent the science of materials. The first of these experiments is presented in chapter five, where the form of the cube is used to investigate particular aspects of materiality and consider how the nature of materials can be revealed through encounter.

Chapter six builds on the methodologies established in chapter four and presents a set of isomorphic tuning forks as material-objects. The tuning forks are used to explore the acoustic properties of materials and generate an experience that attempts to demonstrate the effect of the science of materials on object function.

The seventh chapter of this thesis explores a set of isomorphic bells that, like the tuning forks, are used to demonstrate through encounter the materials science underpinning the acoustic properties of an object. The status of the bell as being further toward the object end of the material-object continuum is highlighted to show how the selection of the isomorphic form is not only relevant to the material function but to its cultural function.

Chapter eight introduces the form of the spoon and describes the isomorphic method of material-object creation used to formally investigate the taste of inedible materials. The high cultural currency of the object and formal scientific investigation into the properties of their materials make the set of spoons the culmination of the experimental investigations of material-objects and their potential for the representation of the science of materials.

The final experimental chapter of this thesis, chapter nine, deals with the experiments with encounters that constitute events staged with material-objects in the public domain over the course of this thesis project.

Chapter ten draws together the themes and work of this thesis in the form of the discussion. Further examination of an object theory is provided alongside the presentation of the material-object continuum as its resultant nexus as a conceptual framework for the practice-led mapping of materials that is the generation of a materials library. The role of the swatch is discussed in the light of the isomorphic sets of material-objects and their encounter. The discussion also examines the role of encounters in the exchange of material knowledge and the importance of the expert within encounters for the revelation and communication of aspects of the science of materials.

A final concluding chapter then outlines the discoveries of this thesis as original work.

Some of the work of this thesis has been published in conference proceeding and formed the basis of invited talks, presentations and exhibitions at conferences, galleries and museums. A comprehensive list of all of these endeavours is provided in Appendix A of this thesis. A glossary of specific terms used and introduced in this theses is provided in Appendix J.

Chapter 2

Literature Survey

This chapter provides an overview of the main materials libraries that are currently in existence, introducing their collections and their methodologies. It will also introduces literature and information sources that deal with materials for the scientific and artistic communities, demonstrating the nature of the relationships practitioners within these field have with materials.

2.1 Defining Materials

The question of what a material is and how it is defined, lies at the heart of the materials selection, identification and utilisation, and thus at the centre of a materials library. However much of the literature that reports on and discusses specific aspects of materials, from both the point-of-view of the sciences and the arts, does not directly or specifically address the definition of a material. The next few sections address this question, but as will become clear, defining a material is in general, problematic.

Dictionary and encyclopaedia definitions focus their attention on the role of materials as the 'stuff' that things are made from and out of (OED, 1999):

> **material** • **n.** **1** the matter from which a thing is or can be made. ▶ Items needed for an activity. **2** information or ideas for use in creating a book, performance, or other work. **3** cloth or fabric. **4** a person of a specified quality or suitability: *he's not really Olympic material.* • **adj.** **1** denoting or consisting of physical objects rather than the mind or spirit: *the material world.* **2** important; essential; relevant: *the insects did not do any material damage.* **3** philosophy: concerned with the matter of reasoning, not its form. –DERIVATIVES **materiality** n. –ORIGIN ME: from late L. *materiaalis*, from L. *materia* 'matter'. (OED, 1999)

In the arts, what often occurs is a form of definition by default, where the word ‘material(s)’ is used descriptively to denote the components of a work, product or building. For example, a text may talk of the dominant *material* in a structure being wood, or that the artist Joseph Beuys repeatedly uses *materials* like wax, fat, felt and honey –denoting that wood, wax, fat, felt and honey are the materials[1]. In these cases, the material is being referred to, understood, and in turn defined as the matter or substance used to create objects or products. A material becomes the input in the process of physical construction that influences the properties of that which is constructed as a result of the material’s embedded ‘materiality’. This materiality is associated with classifications ranging from a qualitative aesthetic, sensorial, and behavioural appreciation of a material, to the specific cultural resonance of a material and its ability to connote meaning.

In more scientifically orientated texts, the definition of a material starts with a description of the chemistry, otherwise called the composition of a material. This is defined rigorously and quantitatively in terms of the type and weight fraction of different types of atomic elements present in a material. There are a finite number of stable elements that make up all known materials; these are shown on the Periodic Table (see figure 2.1). The elements are arranged in order of their atomic numbers, from the lightest to the heaviest, with the atomic number corresponding to the number of protons present within the nucleus of each atom. There are formal subdivisions of Groups (elements within the same vertical columns) and Periods (elements within the same horizontal rows). Each new period corresponds to new a subatomic arrangement of electrons called an electron shell. The Groups thus describe elements with similar outer electron shells which in many cases leads to similar properties. For example, all elements within group IA (the alkali metals) have low densities and melting points, are silvery in appearance, tarnish easily and exhibit high reactivity with water. The reactivity of the alkaline metals contrasts to the Noble gasses which are extremely stable unreactive elements, as a result of having full outer shells of electrons, hence being located in the last column of the Periodic Table.

The chemical composition of a material does not unambiguously define its ‘materiality’. For instance hydrogen and oxygen atoms can combine to form H_20 molecules, however whether this material is manifest as a solid (ice), a liquid (water) or as gas (steam) depends on both temperature and pressure. Similarly, atoms of carbon may manifest themselves as the solid graphite: a black, soft, electrically conductive material; or as diamond: a transparent, hard,

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[1] “Wood, wax, felt and honey”, are found within Joseph Beuys’ work *Vitrine I – V* in Tate Modern, London, 2007, and are listed in the descriptive text for the art work.

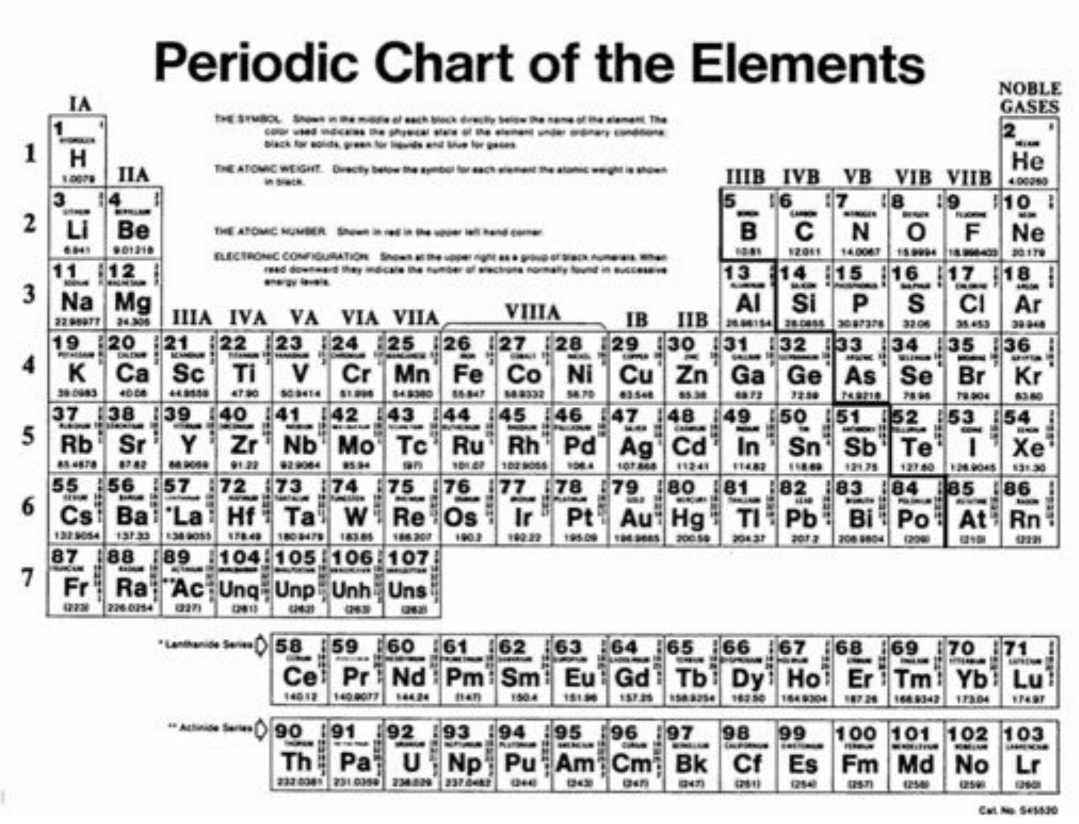

Figure 2.1: The Periodic Table

electrical insulator. Graphite and diamond have identical chemical composition but different crystal structures and very different characters. Thus it is necessary to define both composition (the types of atoms) and structure (how they are arranged) when referring to materials. The only problem with this description of materials from a scientific standpoint is that atoms are so small that most materials of interest contain at least 1,000,000,000,000,000,000,000,000 atoms. The number of ways of arranging that many atoms is so immense that uniquely defining the term 'structure' is highly problematic.

Materials science, as a discipline, is the study of the structure of the arrangement of atoms at different scales of magnification as shown in figure 2.2. Materials science became possible because scientific instruments were developed to enable the observation of structure at different scales, firstly through the optical microscope, then through electron microscopes, atom force microscopes and a myriad of other techniques (Cotterill, 1985). Figure 2.2 shows the macro-structure of a metal alloy tube which shows clearly a large crystal present in a matrix of smaller crystals which can be seen more clearly again in the micro-structure image. By zooming in further to the nano-scale we see a crystal boundary in contact with a nano-particle. A further increase in magnification reveals the regular patterns of individual atoms (each one can be

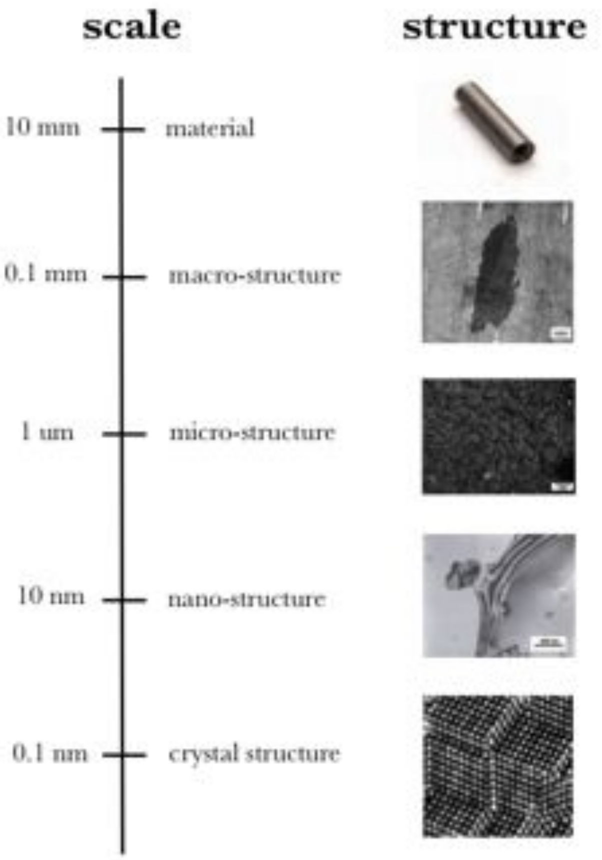

Figure 2.2: A schematic of how different structures correspond to scale of a material, in this case a nickel superalloy tube. Note that the upper scale is not a limit.

identified in the Periodic Table) that make up metal crystals. All materials possess this multi-scale structure, including bio-materials which are perhaps more familiar with the different scales, eg. DNA, cell nuclei, cells, tissues, etc. The structures at all scales influence the elasticity, conductivity and many other properties of the materials. It is a central tenet of materials science that a particular structure will always yield a particular set of properties, so control of structure yields the control of properties (e.g. colour, magnetism, toughness, etc.). This methodology is how properties such as the strength of steel and the electronic properties of silicon chips and all modern materials, came to be understood and controlled. It is also one of the major driving forces behind the drive to develop nanotechnology. However figure 2.2 does not illustrate an important aspect of material structure, namely, that it is constantly changing. These changes usually result in the degradation of materials' properties, such as the discolouring and cracking of polymers, or metal fatigue of aircraft wings. For a more in-depth exploration of scale in relation to materials science see William Callister's book *Fundamentals of Materials Science and Engineering: An Integrated Approach* (Callister, 2005).

Figure 2.2 does however highlight another problem with the scientific approach to materials, namely at what scale does a material become a structure? If we continue the scale bar upwards, we encounter many objects with increasing level of complexity, it is not obvious at what cut-off scale, we consider something to be a 'material' with its inherent micro-scale and nano-scale complexity, and when it is something else, an object or a building for instance. Is a silicon chip a material or an electronic machine for instance? Is a nano-dot a material? Can a single atom be material? If not, how many atoms are require to create a material?

Despite this ontological problem, and also the huge range of possible structures and chemical compositions possible, there are broad categories of structure that exhibit behaviour similar enough to allow certain materials classifications. The six categories of solid material commonly recognised are metals, ceramics, polymers, composites, semiconductors and biomaterials (Callister, 2005). These characterisations largely correspond to the types of bonding present at the atomic scale (sub-atomic structure). However they are not definitive and there are plenty of metals that behave like ceramics or composites, and vice versa.

2.2 Materials and their Selection

2.2.1 The Science and Engineering Approach

Material Science and Engineering are disciplines that revolve around the development, testing, and utilisation of materials. The process of materials selection brings into focus the nature of this relationship, as the structure, properties and behaviours of materials are researched and quantified in order to predict the specifics of how a material will perform. The establishment of definable terminology insures that information about a material is communicated in an exact manner: to talk of strength verses stiffness, for example, is not a semantic exercise but a precise quantitative description of mechanical behaviour: strength is defined as a resistance to crack propagation, whilst stiffness is the resistance to shape deformation (Callister, 2005). These concepts of strength and stiffness are also divorced from the scale of material sample, so the stiffness of a paper clip is defined to the same as the stiffness of a girder if they are made from exactly the same material, and is referred to as an intrinsic material property (although there is now a growing appreciation that there are size effects at the nanoscale).

Processes of testing that provide the definitions of the terminology of materials and their mechanical behaviours are carried out for two main reasons: to simulate the conditions in which a material will be used and therefore “predict its *service performance*”; and to gather “engineering *design data*” and check that the material meets its specifications (Martin, 2002).

Information on the properties of materials is collected in databases. One such database is the Cambridge Engineering Selector (CES) that offers the user the opportunity for the “rational selection of engineering materials and processes” through computational methods (GrantaDesign, 2007). The system was developed within Cambridge University by Michael Ashby and his colleagues and has now become part of Granta Design’s commercial materials selection package, offering materials selection information solutions to engineers, designers, and other materials specialists. Granta Design state that the CES can offer the following advantages to users:

> “CES selectors can:
>
> - Support early-stage design of products where materials and processing options are open.
> - Advance detailed design tasks when coupled to your own custom databases or specialist databases such as MMPDS (Mil-Handbook-5) or Campus Plastics.
> - Redesign components, selecting better materials technology to meet lowest “cost per unit of function”.
> - Find equivalents or substitutes for a redundant or withdrawn material.
> - Find substitutes for a material that has failed in use.
> - Validate a design approach, demonstrating that no material or processing option has been overlooked.
> - Communicate and gain support for new material and processing ideas within an organisation.
> - Improve the design process by encouraging early consideration of material and manufacturing issues in new product design” (GrantaDesign, 2007)

CES allows the user to access information on materials and manufacturing processes; beginning by asking questions like; “what is the function” of that which I am trying to make/design and then, “what objectives need to be optimised and what constraints must be satisfied?” – which aid the development of effective designed solutions. The process of questioning, as an integral part of the design process, is demonstrated when selecting materials for a car body panel; “a car body panel (function) needs to be as light as possible (objective) for a specified stiffness and cost (constraint)”. The advantages of this as a procedure for materials selection are that it allows the users to systematise the process and “focus on the product objectives” in a rational and “unbiased” manner (GrantaDesign, 2007). In utilising the CES package it is crucial not to underestimate the importance of also asking the right questions of the selector and screening the results it generates, for no matter how keenly the design objectives are honed, the findings must be critically analysed. In order to help the user do this, CES provides graphic outputs that plot the properties of materials, and physically group together on the diagram similarly behaving materials.

This type of materials selection is not infallible. In his 1976 book *The New Science of Strong Materials: or Why We Don't Fall Through the Floor*, J.E Gordon looks at the science of materials with an understanding of their existing within a wider cultural context. During his explanation of beam theory and its applications, Gordon tells the story of HMS Wolf, a Royal Navy destroyer that, in 1903, was assigned to the task of being tested for strength (Gordon, 1976, p61). Gordon reports that Navel architects were keen to see if their calculations, that used beam theory to gauge the strength of ships, were in fact correct. Strain-gauges were attached and measurements taken across the steel hull before, during and after a ferocious spell at sea. The researchers found no evidence that the stress experienced by the hull was anywhere near those required to fracture the steel, but curiously ships continued to break in half (Gordon, 1976, p61). Gordon goes on to explain how the tests on HMS Wolf were carried out before the phenomenon of 'stress-concentration' was identified in 1913 and so it was therefore not surprising that the test results were seen to support the beam theory calculations. Gordon suggests that if the strain-gauges had been placed close to the edge of any significant openings in the hull, anomalies in the measurement would have provided evidence of stress-concentration and perhaps led to the discovery of the phenomenon some ten years earlier (Gordon, 1976, p62). The significance of this story also lies in its ability to demonstrate differences between calculated material behaviours and resultant behaviours of a material when in use.

Through outlining how advances in techniques and technologies have gone hand in hand with the understanding of a material's properties and behaviours, Gordon demonstrates that 'feats' of engineering have a two-way relationship with the body of scientific knowledge that surround a material. When created in laboratory conditions, the questions that are asked of a material may vary from those that are put to it out of the laboratory. Gordon reminds the reader that despite testing and re-testing, the final test for each material is the engineering application itself and that if something goes wrong with a structure, the interrogation of the materials and how they were used can lead to a greater understanding of the advantages and disadvantages of different materials.

2.2.2 The Arts Approach

The selection of materials by any member of a creative profession is subject to a variety of processes and various criteria are taken into consideration. It is not possible to make an over-arching statement about these procedures. However, it is possible to identify many areas that influence the selection *and rejection* of a material, by a person working within a creative profession, that differ from the factors that influence the selection of materials by an engineer.

The following list outlines a number of the modes of operation for materials selection within The Arts and loosely differentiates between a number of fields, in order to effectively cover a multitude of the factors that influence material selection. These are by no means divisions with concrete borders, for factors that are important to a craftsperson may indeed be just as important to both an artist and an architect. However, there are different elements that dominate in each scenario and help to demonstrate the plethora of relationships the creative professions have to materials. The selection of the following practices also serves to identify some of the types of arts practitioners that are current users of materials libraries.

The Product Designer

The product designer's relationship to materials can be a two stranded affair. The designer may have a good idea of what material or material characteristics he or she is looking for, as they have already created the design and are now looking for the material that fits the brief. In this first instance the designer may turn to swatches of materials samples that can be easily thumbed through to find a material that is suitable for their design, and liaise with manufacturers to discuss processes and materials solutions. Alternatively, the design process may be in its infancy (if started) and the selection of a material is to be an integral part of the inspiration for the item it creates. In this second instance a variety of disparate sources may be explored by the product designer in order to discover new, innovative or unusual materials –the hope being that they will fire the imagination and inspire the creative process. Marc Esslinger's article *Touching the Senses: Materials and Haptics in the Design Process* declares that "in the early creative phase, many different materials are tried out -touched, bent and glued- in order to find inspiration for new ideas. Of course, a silk DVD player is pure fantasy; however an unencumbered approach can help to adapt elements of various materials stylistically into the design language" (Esslinger, 2006, p33). He offers figure 2.3 to illustrate the designer's relationship to the haptic experience, and provides the following caption; "to test the haptic experience, the 'Frog Design' agency works with different material samples" (Esslinger, 2006, p32).

There comes a point however when the design of a successful product relies upon more than materials desire and approximation. A design training does not generally provide an in-depth scientific knowledge of materials, but more and more designers are taking it upon themselves to gain a greater understanding of the broader materials picture. Wishing to discover "how plastic is made" or "which metals are good for you to eat and which are not" leads many product designers to ask "many material science questions, and set out to answer them in the only way we know how: Google" (Berger and Hawthorne, 2008, p7). The materials science and

Figure 2.3: Figure provided in Touching the Senses to illustrate the designer's relationship to the haptic experience

engineering model of materials selection, with formal terminology and mathematics, is often difficult to access and assimilate into projects by many designers and those coming to materials from an arts background (Ashby and Johnson, 2002). With this in mind, Michael Ashby and Kara Johnson have written *Materials and Design: the Art and Science of Materials Selection in Product Design* in an attempt to bridge the gap between the approach of designers and engineers in relation to materials.

In essence the *Materials and Design: the Art and Science of Materials Selection in Product Design* is divided into two halves. The first part serves to identify what design processes *are* and how the knowledge base of material science and engineering sits within a the matrix of successful design solutions; it can be read as an introduction to design for the engineer, or equally an induction into the engineering and materials science for the designer. The text makes clear that knowledge of materials is part and parcel of successful design. Ashby and Johnson propose that selection of materials for product design should be a multifaceted process of questioning and knowledge assimilation where an understanding the scientific principles serves to advance design solutions. Case studies are provided within the text in order to track the relationship between the product, its design and its materials. The dining chair is used to demonstrate the influence of materials on the forms an object can take, or in other words the fact that "once the material is chosen the form is constrained"(Ashby and Johnson, 2002, p101). If one is determined to make the chair out of solid wood for example, one is typically constrained to construction via machining, whereas if one decides to make the chair from stainless steel one can machine, cast, sheet-form or draw-form the object, resulting in a wider variety of shapes that can be efficiently created. Ashby and Johnson imply that this knowledge of materials and processes makes for better design: an understanding of limitations allows for the thorough exploration of possibilities and the pushing of boundaries. The rationale could be summarised by saying that for the designer to use materials successfully, they have to understand all aspects of the territory in which they are operating. In order to provide as much interdisciplinary materials information as possible and map this territory, the second half of *Materials and Design: the Art and Science of Materials Selection in Product Design* provides "A Practical Reference for Inspiration". This section profiles of a wide range of materials, processes of shaping, joining and surfacing materials, offering discursive examples of actual designed products with relevant materials science.

Throughout the book, Ashby and Johnson bring quantitative analysis and qualitative attributes together for the designer to make informed materials selection decisions. They generate accessible graphical information that plots technical attributes and offers the opportunity of visual comprehension of scientific data sets. An example of just such a multi-dimensional scaling (MDS) map can be seen in figure 2.4, where acoustic brightness is plotted against acoustic pitch and classes of materials are grouped to show correlation of material trends in acoustic properties (Ashby and Johnson, 2002, p72).

'Materials in Design' has recently become the focus of much academic and commercial effort as evidenced by the new 100%Materials show which is now a permanent fixture of London Design Week and the expanding number of materials guides for designers (Bramston, 2009) and (Parsons, 2009). Perhaps the most effective of these is the series of books by Chris Lefteri that go under the banner of *Materials for Inspirational Design* (Lefteri, 2007a). In his books, Lefteri, a product designer and lecturer at Central Saint Martin's College of Art and Design, embraces materiality and represents it for a design audience, focusing attention on the following categories of materials: plastics (Lefteri, 2002) and (Lefteri, 2006), ceramics (Lefteri, 2003), metals (Lefteri, 2004a), glass (Lefteri, 2004b), and woods (Lefteri, 2005). Each book takes one class of materials in turn and introduces innovative and/or interesting products that have utilised a form of this material. The format of each book is the same. One product/item is exhibited on each page and accompanied by a small amount of text in order to illustrate a specific aspect of the material. In the *Metals* book for example, the property of "memory" is illustrated and explained. Six photographs show the progression of a bent piece of wire forming into a paperclip. The text explains that this is a "Nitinol thermal shape memory alloy paperclip" that can be bent into any configuration and then when a current is passed through, the wire returns to the form of a paperclip (Lefteri, 2004a, p62-62). There is no micro level explanation of the behaviours of the

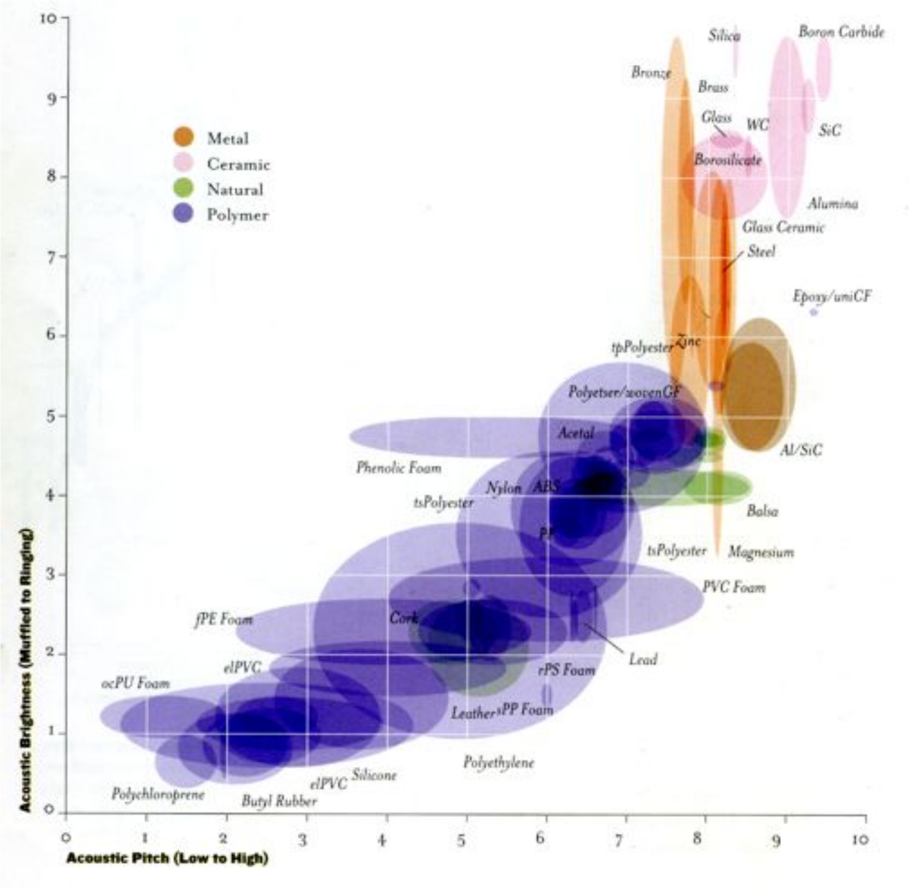

Figure 2.4: The Ashby and Johnson MDS map of acoustic properties.

nitinol crystals, nor a general scientific discussion of why this phenomenon occurs, but the author does give a list of the key features of the material, web links to manufacturers and examples of typical applications of the product. In *Wood: Materials for Inspirational Design*, Lefteri explores the diverse nature of the material and the processes and treatments that can be applied to it. Categories for exploration are given, ranging from “How to Buy Wood” and “Hardwoods” as well as “Technical Information” (Lefteri, 2005). These technical details on materials can be found in the back of each book in the series and compiled into accessible tables and charts that allow easy comparison of materials. In his latest book *Making It*, Lefteri continues his materially-orientated approach but provides a more in depth introduction to manufacturing techniques and technologies for product design (Lefteri, 2007b).

Lefteri’s texts are akin to a swatch of materials, offering an array of possibilities that tantalise and provoke curiosity through the presentation of small samples. The ability of the text to aid materials selection is limited but the books do cover a broad spectrum of materials. In discussing how each of the materials has been utilised, Lefteri introduces the reader to the multi-functional nature of materials, offering a way into an appreciation of materiality as a factor that influences function and the success of design.

The Architect

Like the designer, the architect's relationship to materials can also involve haptic encounter and the phenomenon of the swatch, but it is distinguished by a number of other factors. Within an architect's training, formal direction is taken in engineering, materials and mathematics, introducing the practitioner to formal concepts familiar to the engineer. Strength, elasticity and ductility for example need to be taken into account when designing and specifying supports for any architectural structure to ensure that the building will be stable. If the architect does not have an adequate grasp of these principles, the design that they create may never be able to be built. In order to service the technical needs of architects, manuals like *Materials, Structures and Standards* (McMorrough, 2006) provide tables of materials; listing properties, forming and joining methods, applicable surface finishes and size availability. The use of mathematics however is minimal, with descriptions of properties taking priority over quantitative specifics. Within a quick reference list McMorrough writes for magnesium; "strong and lightweight; as an alloy, serves to increase strength and corrosion resistance in aluminium. Often used in aircraft, but too expensive for construction" (McMorrough, 2006, p213). Properties of 'strength' and 'resistance to corrosion' are stated but no scientific explanation is given here, or later in the text, of what these properties mean in relation to materials science, in other words, what is the relationship between the micro-structure of the material an its macro-properties. In the *Basics* architectural companion series, the *Materials* volume offers the following figure (see 2.5) in an attempt to map the properties of materials. Materials Science is not directly referenced but represented in the form of 'technical properties' and subdivided in the category of 'building science', 'mechanical' and 'chemical'. The accompanying text states; "architects are not expected to be familiar with all these properties in detail, but they should be aware of connections and consequences" (Hegger et al., 2006, p12), demonstrating an awareness of the interdependent and relational nature of material properties.

If something fails in a building once it is built, a degree of responsibility may be placed with the architects. This means that architects adopt a risk-averse strategy when it comes to materials selection (Miodownik, 2005). Whilst they may be willing to design never before seen shapes, they are less likely to take chances with the materials used for construction. Indeed, the processes required in order to have a 'new' building material tested and certified as safe for structural use, are costly in both time and money, two things that are often dominant

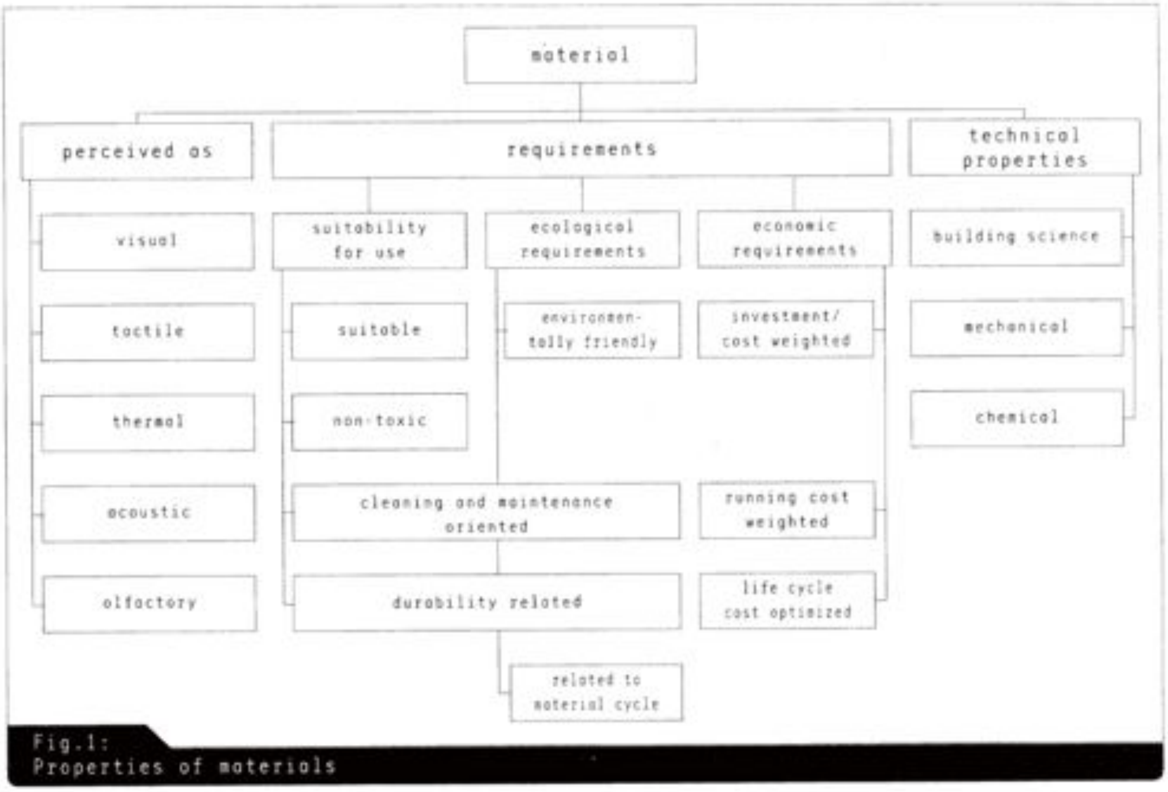

Figure 2.5: Schema of material properties for architects (Hegger et al., 2007, p11).

constraints in an architect's brief. McMorrough's reference to magnesium being 'too expensive for construction' enforces cost as an influencing factor for architects when selecting materials. The environmental impact/cost of materials used, process undertaken and efficiency of the final building's energy consumption, the embedded energy, are also becoming increasingly important in the designing and constructing new buildings.[2] The *Construction Materials Manual* offers colour thumbnail photographs of different species of woods, enabling comparisons of colour and the visual characteristics of grain. The text states that "aesthetic considerations and preservation aspects must be harmonised when choosing a type of wood" (Hegger et al., 2006, p69), demonstrating that not only must the architect consider the appearance of the wood selected, but balance the environmental impact of felling, growing and sustaining trees.

The pragmatism that is engendered by the responsibilities of materials selection can result in aesthetic compromise, but for some architects, such limitations and problems open doors for creative solutions (Beylerian and Dent, 2007) and (Brownell, 2006). Innovation in the finishes and

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[2] As of August 2007 every home with four or more bedrooms put up for sale is required by UK law to provide a Home Information Pack. Within this is an Energy Performance Certificate that crate by "an accredited Energy Assessor". This places the energy cost of the home on the economic agenda of house buying and construction. (http://www.homeinformationpacks.gov.uk)

treatments of materials offer the architect a broader palette of possibilities when selecting materials by aesthetic criteria. For example, applying a cladding skin to the face of a building, that is not part of the structural apparatus, means that experimental materials, incapable of supporting weight, can be used to alter the appearance and perception of the building (Miodownik, 2005). In some cases, materials are selected for cladding in order to shift the sensorial perception of a building. To face a concrete surface with a wooden veneer instantly brings some of the aesthetic and haptic properties of wood to a concrete structure. Incongruence in such sensorial perception can be used to generate interesting architectural effects, for where "anticipated sensations are missing, the sense of disturbance becomes a [designed] experience" (Hegger et al., 2007, p16). Equally two signature characteristics of two disparate materials could be combined to generate an architectural experience. An example of this can be seen in The National Theatre on London's South Bank, where the unclad structure is built from concrete beams that were cast in between wooden planks, resulting in the grain of the wood embossing itself on the surface of the concrete. The result is a concrete building that conforms to the grey colourisation expected of concrete but offers the textual paternation associated with wood.

The Craftsperson

The craftsperson's story, in relation to materials, differs dramatically from the architect's in one major respect, that of scale (Risatti, 2007) and (Adamson, 2007). If one considers the act of throwing a pot in contrast to the creation of a skyscraper, not only is the size of the final outcome starkly different, but the scale of operation is wildly contrasting.[3] An architect requires a substantial labour force to produce a finished building, whereas a craft object is more often than not the solo creation of a single pair of hands. This shift to the small scale utilisation of materials enables individual practitioners the ability to experiment with materials, by virtue of simply having less of it to work.

The materials used in many crafts are encountered with immediacy and tactility, selected literally by the hand, as opposed to specified over the phone or agreed on in catalogues, meaning that *feel* is at the heart of the craftsperson's relationship to materials (Dormer, 1997) and (Adamson, 2007). The development of craft skills, no matter to what sphere of practice they be

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[3] Consider for a moment Bankside Power Station in London, now Tate Modern. The construction of the original power station followed the plans of architect of Sir Giles Gilbert Scott but were followed by scores of engineers and builders. Each one of the 4 million bricks that make up that structure were laid by hand. The size of the standard brick is designed to fit neatly into the worker's hand. It is possible therefore to consider the structure of Bankside Power Station as a handmade object, indeed, a craft object. Richard Sennett, writing on The Craftsman said on the history of the brick "that it shows the way anonymous workers can leave traces of themselves in inanimate things" (Sennett, 2008).

applied, depends upon a "deep knowledge of materials" that "comes from experience in handling and processing them" (Ward, 2008). This in turn informs the practitioner's ability to *know* their material as the knowledge is haptic and comes from repeated encounter with and exploration of, the physicality of the matter. In some craft-based professions apprenticeship schemes form part of the process of the acquisition of materials and skills knowledge. In carpentry for example, the carpenter may show the new apprentice the grain of a wood and explain the effects that working with and against the grain can have on how the material behaves. The apprentice is typically encouraged to experience these properties of wood by splitting and sawing timbers, trying out different tools and techniques, supporting theoretical explanation of the material's behaviour with the physical act of doing and actual encounter of that behaviour.

The craftsperson's relationship to materials is so embedded in their practice that it frequently defines it, with the naming of the practitioner often resulting from the type of practice undertaken or the type of object created. Silversmiths being those who work with silver, ceramists being those who use and fire clay, and so on for brick layer, metal worker, glass blower –all professions that express a heavy sense of materiality in their names and are either directly adopted from, or pertain to, the material they work with.

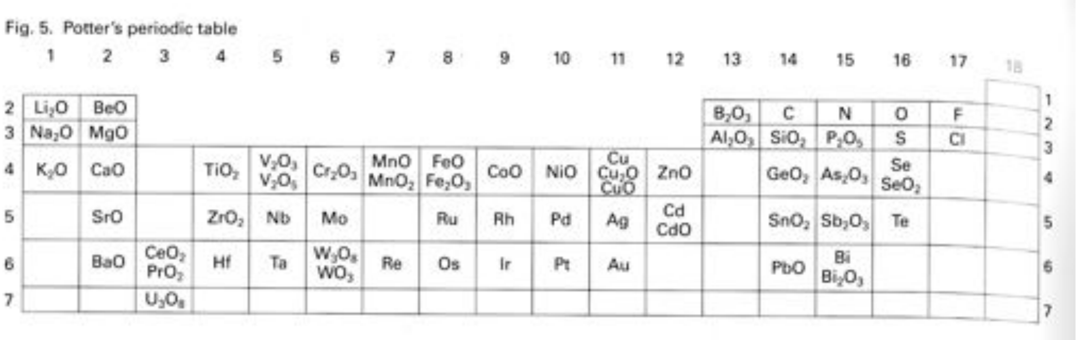

Fig. 5. Potter's periodic table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
																			1
2	Li_2O	BeO											B_2O_3	C	N	O	F		2
3	Na_2O	MgO											Al_2O_3	SiO_2	P_2O_5	S	Cl		3
4	K_2O	CaO		TiO_2	V_2O_3 V_2O_5	Cr_2O_3	MnO MnO_2	FeO Fe_2O_3	CoO	NiO	Cu Cu_2O CuO	ZnO		GeO_2	As_2O_3	Se SeO_2			4
5		SrO		ZrO_2	Nb	Mo		Ru	Rh	Pd	Ag	Cd CdO		SnO_2	Sb_2O_3	Te			5
6		BaO	CeO_2 PrO_2	Hf	Ta	W_3O_8 WO_3	Re	Os	Ir	Pt	Au			PbO	Bi Bi_2O_3				6
7			U_3O_8																7

Figure 2.6: The potter's periodic table, showing both elements and oxides (Hamer and Hamer, 2004, p260).

In order to aid the craftsperson in their endeavours, manuals and encyclopaedia offer access to information on materials that pertain to their mode of operation, fore-grounding the individual experimentalist as materials manipulator (Hamer and Hamer, 2004) and (Farmer, 1975). *The Potter's Dictionary of Materials and Techniques* by Frank and Janet Hamer is just such a reference work that regards itself to be for "all those who want to make things with creativity, imagination and an understanding of why it works the way it does" (Hamer and Hamer, 2004, p1). The contents of the dictionary range from definitions of substances like 'catalysts' and 'malachite', where relevance to ceramic production is described and scientific agency discussed, to explanations of processes like ‘workability’ and ‘oxidisation’ in relation to the practical activities of both the potter at the macro level and the chemical reactions on the micro level. Nowhere is the presence of this technical information more evident than in the section on the Periodic Table (Hamer and Hamer, 2004, p253-262). Not only is a detailed scientific explanation of the table provided, but the authors dedicate six pages to the relevance of the Periodic Table to ceramics and the practice of the potter. Figure 2.6 shows a specific periodic table for potters, where only the oxides and elements involved in ceramics are included and the “general chemistry principle of the Periodic Table of elements engender parallel principles in the potter’s Periodic Table” (Hamer and Hamer, 2004, p256). Calcium Oxide (CaO located in group 2 of period 4 in 2.6 and commonly known as lime) is a key substance for ceramics, being “used as a filler in low-temperature bodies and glazes: and as a flux in high-temperature glazes” with large amounts encouraging crystalline growth during the cooling process (Hamer and Hamer, 2004, p47). The text goes on to explain that:

> An important point about calcium oxide is its stable structure during firing. The melting point of the metal calcium is $852^oC(1566^oF)$ but the melting point of the oxide is $2570^oC(4658^oF)$. The ions of calcium and oxygen make a strong bond, each in a six-fold co-ordination as shown in the drawing. In interaction with other oxides, and especially over $1100^oC(2012^oF)$, these bonds can be loosened. Hence its fluxing action, but it is impossible to completely separate the calcium from the oxygen by reduction below $2200^oC(3992^oF)$. Calcium oxide is therefore suitable for all glazes and is unaffected by deliberately or accidentally reducing atmospheres.” (Hamer and Hamer, 2004, p47-48)

This explanation demonstrates the integration of chemistry and the principles of the materials science paradigm into the practical knowledge base for the potter. The acknowledgement of accidental actions demonstrates an understanding of the nature of a creative and experimental practice, whilst the description of bonds and molecular behaviours provides explanation of the chemical interactions.

The Artist

The artist can be considered in relation to the type of practice, the things that are made as a result of this practice, and the materials employed. For example, a sculptor derives their title from the act of giving form to matter in space, and the painter, film-maker and body-artist are all named after the material with which they work. Like the craftsperson, the artist is often conceived of as a solo practitioner. This is by no means the only mode of operation and ignores the support teams who are often involved with large scale installations, or assistants charged with practical contributions to works, and technicians called upon to provide specialist assistance with technique, processes and materials. For example, the contribution of the Mike Smith Studio to the creation of Rachel Whiteread's 2001 work *Monument* for the fourth plinth of London's Trafalgar Square is often ignored when the authorship of the sculpture is discussed[4] (Whiteread, 2005). The concept of the artist as a solo practitioner does however enable an analysis of their practice in relation to hands-on endeavours that facilitate the acquisition of a haptic knowledge base.

Within general fine art practice the aesthetic properties of materials can be seen as one of the most important factors influencing their selection (Gombrich, 1990). The desire for visual effects certainly defines the artist's relationship to pigments, prompting the exploration of, and experimentation with, the aesthetic possibilities that materials afford (Ball, 2003). Yves Klein's creation *International Klein Blue* (IKB), is in essence pigment as art.[5] The effect of the painting is to immerse the viewer in pure colour with complete absence of representation. Sophie Howarth writes for Tate Modern that IKB has "a quality close to pure space" that Klein "associated it with immaterial values beyond what can be seen or touched" (Howarth, 2007), demonstrating the immersive effect of a material property –the ability to absorb and omit light of specific wavelengths. There are many artists who have been known for the use of particular pigments, as well as those who have discovered pigments and processes (Ball, 2003).

Apart from the *feel* and aesthetics of a material, an artist my also select and reject materials for their connotative power. If, in the generation of art, the artist is less concerned with the making of functional objects and more concerned with the making of meanings, the role of the material as conveyer of meaning is crucial. Damien Hirst's recent work *For the Love of God* (see figure 2.7), is a human skull cast in platinum and encrusted with 8,601 diamonds. The use

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[4] Mike Smith and his team at Mike Smith Studio (www.mikesmithstudio.com) played a central role in the design and fabrication of Whiteread's inverted plinth. Without the creative and technical input of the studio, Whiteread's work would not have been realised. "The casting was very complex due to the demanding nature of the material and required the fabrication of two inner and two outer moulds. After several test castings it was determined that aluminium would best suit the fabrication of these moulds due to its thermal conductive properties which also gave an excellent surface finish to the resin. Rubber gaskets were used for sealing the sections of the inner moulds. The fabrication of the outer moulds involved considerable and complicated folding and forming of the aluminium extrusions in order to replicate all of the decorative details of the original plinth. Mild steel was chosen for the structural work surrounding the outer moulds and for the internal hydraulic jack mechanism because of its strength" (Smith, 2001). Documentation can be viewed at www.mikesmithstudio.com/projects/flash/indexprojectsflash.htm

[5] *IKB 79* Yves Klein, 1959, is owned by Tate and displayed on a rotational basis at Tate Modern, London. Close examination of the incased works reveals specks of pigment lying at the bottom of the glass housing. No illustration is provided in this document as the loose nature of the powder and the overall effect of the painting is something impossible to reproduce in print, as the qualities of the light that are absorbed and reflected off the page are completely different to those absorbed and reflected by the painting.

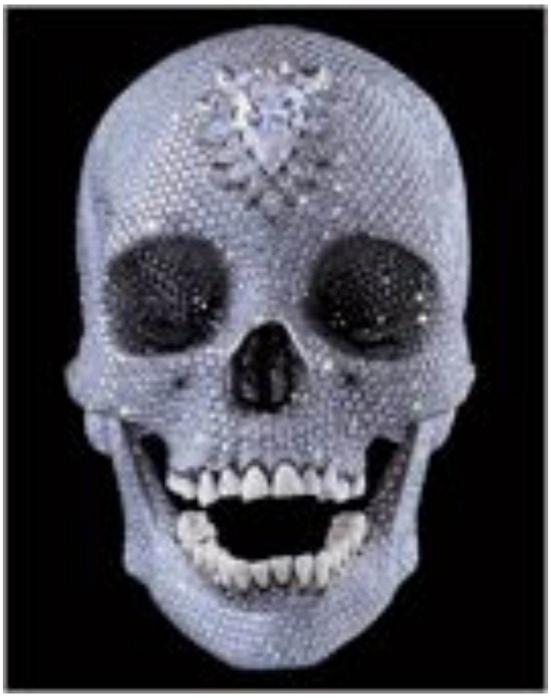

Figure 2.7: *For the Love of God*, by Damien Hirst, 2007.

of such expensive materials prompts questions of value to be asked of the work as its market value transpired to be greater than its material value. (The materials cost £14 million pounds but it was put up for auction with a £50million asking price.[6]) The use of diamonds inspire a number cultural references ranging from states of longevity (forever-ness), to the history of slavery and unethical treatment that has surrounded the mining of diamonds[7]. The importance of the material to the work can be understood if one were to imagine the same idea executed in different materials. How would the meaning shift and work be perceived if the diamonds were cut glass and the platinum replaced by stainless steel, or if the skull was biscuit and the incrustations were chocolate chips? Just such questions can be asked by the artist whose practice embraces materials and combines concept and original object.

Material exploration is central to the practice of many artists and can be seen in works that span centuries and traditions; from the skilful use of marble by ancient Greek sculptors in the creation of works like the Venus De Milo, to the industrially engineered steel structures of Richard Serra and Antony Gormley (Kuhl et al., 2009). Contemporary sculpture, whilst still using many "traditional materials" (Collins, 2009, p170-195), also exploits modern advancements in materials and their technologies for the production of work. For Anish Kapoor, this proves

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[6] http://news.bbc.co.uk/1/hi/entertainment/6712015.stm

[7] The BBC reported in June 2007 that "the diamonds are said to be ethically sourced." Website accessed August 2007: http://news.bbc.co.uk/1/hi/entertainment/6712015.stm

to be one of the principle concerns of his work; investigating "the way in which the language of engineering can be turned into the language of the body" (Kapoor, 2007). Such an approach is evidenced in his large scale work *Marsyas* (2002) which was installed in the Turbine Hall of Tate Modern and comprised of "three steel rings joined together by a single span of PVC membrane" deep red in colour. The design and construction of the work exploited advanced computer modelling and simulation techniques in order to perfect the form and test the merits of the materials from which it could be made. [8]

Material interest is also shown by artists less prone to the making of large scale monumental sculpture. The 1986/7 work of the swiss artists Peter Fischli and David Weiss, *The Way Things Go*, takes a more dynamic, transformative and ephemeral approach to materials. *The Way Things Go*, as a kinetic work, was captured on film and "consists of a number of events linked together in an improbable causal chain.... until, some sort of inflammable foam goes up in smoke and it spills over the lip of a tray" (Danto, 2006). The work has "no function and no goal" (Danto, 2006, p214) but is simply an exploration of the interaction of materials and objects.

Figure 2.8: *Proyecto para un Memorial*, by Oscar Muñoz, 2003-2005. The screen on the left clearly shows the partially evaporated painting of a face.

For architecture and engineering, the failure of a material can be a catastrophic event. In art however, the failure of a material could be the intention of the artist; thus rendering the

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[8] The account of *Marsyas* was taken from the description published by Tate Modern in the accompanying exhibition pamphlet. The text and further information are available on the Tate Modern website in the archive of past exhibitions. www.tate.org.uk/modern/exhibitions/kapoor/

concept of failure redundant, replacing it with an accepted type of functionality. Modes of weathering, corrosion and erosion can all be embraced as the process of a sculpture harmonising with its surrounding. The entropic phenomenon of evaporation is embraced by the Colombian artist Oscar Muñoz, whose recent work *Proyecto para un Memorial* was exhibited at the 2007 international art biennial in Venice. Muñoz's work (see figure 2.8), was a five screen video projection with each screen showing out of phase loops of seven minutes duration. Each screen shows a different face being painted in water onto a stone surface. As soon as the water is applied the marks begin to evaporate, an effect that is a direct result of the materials employed and the physical conditions in which they were being used. The work embraces the impermanent nature of water within the environment, as well as the insulating properties of stone and thus the work functions as a direct result of the material used. Equally, as the materials perform they create the work.

2.2.3 Synthesis

To summarise, materials scientists and engineers select materials using the concept of quantifiable physical properties. These properties are linked to the structure of material, and can be changed by modifying the structure. If a design requires a material with a particular strength, or a particular electrical conductivity, databases exist to search for an existing material with the required properties. If such a material does not exist, the structure of a candidate material may be modified to tailor the properties to that required. If this is not possible, the design can be changed and new properties calculated. The methodology is quantitative and numerical, the entire process is often carried out without the engineer ever touching or seeing the material.

The situation is very different for structures whose performance is not based solely on the physical scientific parameters, but also on sensual, tactile, aesthetic, and cultural factors. Creations such as buildings, interiors, urban spaces, clothes, pens, vacuum cleaners, and mugs, are structures in which human comfort, inspiration, and sensual satisfaction are important. These structures tend to be designed by members of the Arts community, whose relationship to materials selection is very different to that of the engineer and more diverse, with each type of practitioner having different methodologies and traditions. Nevertheless, important themes have emerged from my analysis of these practices. A qualitative tactile, hands-on approach to materials is favoured in many cases. Specific materials expertise, encapsulated through experience and highly technical knowledge, is often the key to Arts practises. However such methods are rarely generalised, nor are they accompanied by the use of the concept of structure-property paradigm of materials science. While quantitative analysis, testing and microscopy is on the increase within the arts as engagement with scientific technologies increases (Ede, 2005) and (Hauser, 2008), the practitioner's relationship to materials is still largely driven by use, manipulation and appreciation of materials on the macro level, from encounters with haptic and aesthetic analysis at the human scale.

2.3 Materials Libraries

The concept of a materials library is a relatively new one. Museums, private collections and Cabinets of Curiosity can offer a heritage to the idea of a materials library as their catalogues and arrangements can take into account the materiality of the items on display (Cummings and Lewandowska, 2000), but the rise of the self declared materials library is on the whole a phenomenon of the last ten years and still something that is finding its theoretical and pedagogical feet. There are fewer than twenty publicly identifiable materials libraries in the world and it is possible to divide these into three types: the commercial venture, the professional resource and the institutional collection. The following section provides a basic overview of a selection of these libraries in order to highlight some of the similarities and differences in their aims, methods and forms.

2.3.1 Commercial Ventures

The materials library as commercial venture is perhaps the most formally established model of the materials library concept. Funding from subscription memberships and/or sponsorship from materials manufacturers and suppliers has meant that comparatively substantial sums of money have been used to create well defined physical and virtual spaces that attempt to address the materials needs of their users. What follows is a description of a number of such enterprises.

Material ConneXion®

Material ConneXion was established in 1997 by George M. Beylerian as a resource for inspiring the creative communities and informing them about innovative materials. The project established itself with a business model that claims to offer something that is "unique as a search mechanism and an incredible time and cost saver for those who are researching and exploring in the materials field". The enterprise's aim is to be a place "where professionals –architects, engineers, industrial and interior designers and manufacturers– access specifications and manufacturers' contact details for the latest, most innovative materials and processes" in order to be inspired, advance and enhance the built and designed environment (ConneXion, 2007).

The two main expressions of the Material ConneXion "vision" are the physical resource in New York and the web-based database. A minimum annual subscription of $200 provides unlimited access for a singular named user to the virtual materials database. A fee of $450 is charged by Material ConneXion for single user membership that allows access to both the database and the physical library in New York. The Material ConneXion web-site makes substantial claims about the nature of its materials resource and the advantages that membership of the library may bring. The resource is described as "a library like no other", "the unique world source that physically and virtually connects users and manufacturers" and that "nowhere in the world have materials been celebrated as they are at Material ConneXion". The library contains "physical samples of more than 2,000 materials and processes with over 3,000 variations" that are selected for inclusion in the collection by a panel of material experts from a cross-section of professions that include material "users" and "producers" who meet on a monthly basis as the Materials ConneXion Jury (ConneXion, 2007).

As well as the materials library, the New York resource contains conference facilities that host an array of lectures, seminars and networking events. There is also a 'new arrivals' wall that displays examples of the latest inventions and products that have been accepted into the collection. Material ConneXion claim that this area "should be your first stop for inspiration". The building also houses a publicly accessible materials gallery that has changing exhibitions that explore the importance and influences of new materials and their possible applications. The location as a whole is pitched as a "highly adventuresome destination" that "exposes the visitor to endless surprises... where all sorts of 'conneXions' take place" (ConneXion, 2007).

Outside of New York, Material ConneXion have offices in Bangkok, Cologne and Milan. Whilst not providing the array of materials or facilities that the American headquarters have, each branch offers a materials consultancy service where "material experts offer market research, exhibit services and other business tools to help address a variety of material challenges" (ConneXion, 2007). The ongoing expansion and development of the services offered internationally by Material ConneXion makes the company one of the high-profile materials library brands. The company market themselves with the slogan "Every Idea Has a Material Solution" demonstrating that they see their service as something that can be applied to a multiplicity of practices and industries looking for creativity and innovation, through and with materials (ConneXion, 2007).

Matério

This Parisian materials library was formed in 2001 and became fully operational in 2003, creating a niche for itself amongst the European creative professions, forging links between practitioners from varied backgrounds though the communal resource of materials, allowing "discoveries, expertise and ideas [to] be mutually and constantly enriched" (Matério, 2007). The emphasis on the community of professionals who can come together in an exchange, with a shared interest in materials, gives Matério a public spirited remit. The resource accepts no corporate or government sponsorship, financing itself exclusively through membership subscriptions, allowing the organisation to maintain its independence. Matério offers three types of annual membership that provide varying levels of access to the collection. The minimum membership fee is €100, which allows access to the showroom and database by appointment only. The next type of membership costs €297 and is a one year license for the use of the web-based database. The most expensive subscription Matério offer is for the "Tout Matério" license that costs €640 and gives the member unlimited access to Matério's showroom in Paris and the web-based database. All members receive the monthly 'materials metre' that compiles into a single metre-long .pdf file, a roundup of the latest new materials to be catalogued by Matério.

For members and non-members, Matério offer a e-newsletter (in French only) that reports on recent research and development news, the latest technologies and processes to effect materials manufacturing and articles of general interest to materials communities. Matério also run material Matinées that take the form of seminars on themes like 'soft materials', 'sustainability' or 'light', where "several professional points of view on the chosen subject are presented" (Matério, 2007). These sessions are free to members and cost between €40 and €70 for non-members.

The physical resource of the Matério "show room"[9] is the materials library that lies at the heart of the project. A space of around one hundred square meters, the showroom contains "several thousand self-service products and material samples... 137 meters of shelving, 12 workstations, 243 storage boxes, 2 sofas and 1 coffee machine" (Matério, 2007). The material samples are labelled so that they can be accessed by visitors who wish to find a specific item as well those who are happy to browse without prior aim. For those looking for a specific item, the first point of call is the virtual database, where all material samples are catalogued. One can look for materials by common or product names, material properties, or by simply browsing pictures. Each material sample is given a reference number that specifies its location within the room. With this, one is able to find the shelf on which the material is situated but it is then left to the

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[9] Show room is the term used by Matério on their web-site to describe the area where the physical material samples are located (Matério, 2007).

user to sort through items within the shelf area, checking each number to determine which one is the specified material. Whilst materials are grouped and arranged, the free-form placement within the specified zones allows for the act of browsing and rummaging to be maintained as an activity that is part of the using experience, even for users who believe they know what they are looking for.

Materia

The Dutch based project, Materia, was founded in 1998 by a group of architects who had a self-confessed idealistic point-of-view with regard to the aims and outcomes of Materia. They describe their "mission" as the drive to "create transparency in this diffuse [materials] jungle" by bringing together relevant information on new materials and the way they are, or can be, used (Materia, 2006). They set about doing this by developing a physical archive of materials that acts as "an interactive platform" for physical interfacing with materials, as well as creating "an ingenious search engine" that connects "creative professionals like architects and designers with producers and product developers" (Materia, 2006). This search engine was launched onto the internet in 2005 under the name of Material Explorer (www.materialexplorere.nl), and offers its users a database that embraces both "sensorial and technical properties as selection criteria", making the information available to users with a variety of material knowledge forms. A screen shot of the initial Material Explorer search page can be seen in figure 2.9 and shows the combination of search parameters that are available to the user. As well as a 'key word' search facility, the user is able to select general sensorial and technical details within a variety of materials categories that are listed on the left of the screen. The central and right hand columns offer drop-down options that allow the user to prioritise a variety of materials properties. Under the 'Sensorial, texture' option the user can chose between the search parameters of 'coarse', 'medium' or 'smooth', whereas under the temperature option the user can choose from 'warm', 'medium' or 'cool'. This format of three ratings of sensation is standard throughout the selection process. For the technical options that are available, the user can select between 'good', 'moderate' and 'poor' when defining the search parameters.

Access to the Material Explorer is free to anyone who registers with the site. The registration process is carried out on-line and requires the user to submit electronic and postal contact details and declare their profession and any specialist materials interests. Those who register their details receive a monthly e-newsletter and are occasionally contacted by Materia with questions regarding how they are using the facilities and whether it is fulfilling the users needs. Whilst this computer-based resource is free, manufacturers are paying Materia to be included on the

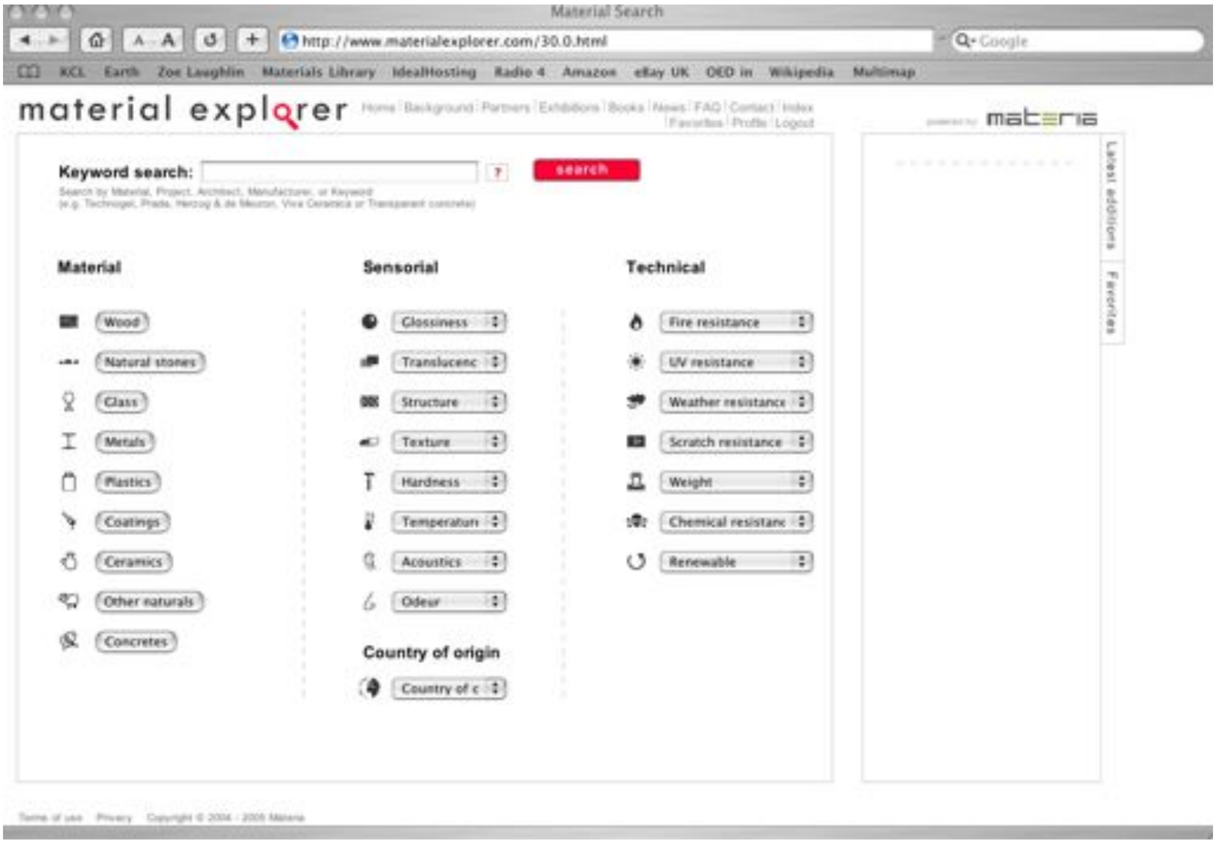

Figure 2.9: A screen shot of the Material Explorer search page.

Material Explorer website, meaning that the information found on the site is not always without commercial bias.

Beyond the database and virtual endeavours of Materia, activities also include the creation of touring materials expositions that seek to provide the visitor with the opportunity “to actually touch, sense and see various recently launched materials which inspire, educate and enhance creativity” (Materia, 2006). Their most successful exhibition to date (with regards to duration of the exhibition and the number of visitors who have seen it) is “Material Skills: The Evolution of Materials”, created in 2002. This collection of materials toured trade-fairs, architecture biennials, design museums and conferences throughout 2005 and 2006, and was seen by an estimated 400,000 people. A book of the same title was published to accompany the exhibition and has reportedly sold 4000 copies (Materia, 2006).

For a fee, and by appointment only, Materia offer access to the Inspiration Centre; “where innovative materials from all over the world can be seen, felt and experienced” for “material is something you need to feel, see, and physically experience” (Materia, 2007). For access to the ‘permanent exhibition’ of materials, Materia require users to pay an annual subscription.

There are three main subscription types; those for ‘creators’, those for ‘producers’ and those for ‘educators’. In all categories, prices range from around €50 to €150 for the solo user, to over €2000 for multi user packages. The Inspiration Centre also offers conference and seminar facilities that can be hired by the day for the user’s own purposes. Alternatively, Materia offer a lecture service within the Inspiration Centre for groups of interested parties like architectural practices, design firms or research teams. Each group can specify a topic or area of interest and receive a bespoke lecture on this from the founder of Materia (Els Zijlstra) for €2500, or for €500 they can experience Ms Zijlstra’s general lecture on innovative materials.

Material Lab

In 2006 the ceramics company H&R Johnson opened Material Lab on Great Titchfield Street in the centre of London. Freely open to the general public and situated just off Oxford Street in a prime commercial location, Material Lab has the appearance of a commercial showroom with samples of products lining the walls but differs from a showroom in one key respect; it is not the point-of-sale for the items on display. Suppliers contact details can be obtained and assistance given in retrieving relevant information on materials, specifications and ordering, but no money is exchanged. If the user is prepared to leave their e-mail address and allow the staff to take a note of which samples they are interested in, one is able to take away, free of charge, many of the items on display.

Figure 2.10: Inside *Material Lab*. This figure shows how the tile samples are of the same size and have been grouped according to their colour. This area of the showroom is titled the ‘Material Specifier’.

The basic premise of the library is to display the latest tiling products to the design communities, along side literature and examples of other developments in the general materials realm.

Figure 2.10 shows the 'Material Specifier' area that runs the length of one wall, where standardised 10cm×10cm tile samples are displayed in order of colour. Material Lab, whilst set up by H&R Johnson, does display the products of other companies, though their policy is to only stock the products of one manufacturer for every type of sample. The ratio of H&R Johnson samples to other manufacturers is roughly three to one, with manufacturers paying up to £10,000 to have a single product included in Material Lab. In return they are guaranteed exclusivity in the display of that product with, for example, one company having the monopoly on glass mosaic tiles, another having the monopoly on polycarbonate sheet. On the back of each tile sample there are labels that indicate a variety of information about the sample, as seen in figure 2.11.

MATERIAL LAB

Range Prismatics -

Reference PRG 6 - Black

Finish Gloss

Slip Resistance n/a

Sizes Available 100x100x6.5mm 150x150x6.5mm 200x100x6.5mm 200x200x6.5mm

Usage Interior Wall

H&R Johnson
Tel: 020 7436 8629

Sample subject to slight shade variation due to the inherent nature of ceramic tile production

MATERIAL LAB
Tel: 020 7436 8629

Range LUXE 97

Description Contract vinyl wallcovering with fabric backing

Roll Size 137cm x 27m. Sold by the linear metre

Fire Rating Class '0' and '1' to BS476

Durability Washable / Scrubbable

Availability 7 – 10 day delivery

Company Details TEKTURA PLC
www.tekturaonline.com

Figure 2.11: Two examples of the labels stuck onto the back of tile samples within Material Lab. The labels provide the user with the manufacturers name, product reference details, specifications of sizes available, suitability of use and performance ratings when known.

Samples of materials greater than $10cm^2$ in dimension can be found, though the types of samples are of materials more suitable for paving and cladding –materials of which clients often wish to see a larger sample. In comparison, Material Lab's 'What's New' section, contains materials with no specified use in non-standardise and non-uniform sizes. This comparatively fluid section is where new and innovative non-tile-based materials are displayed. There is no requirement for these materials to be products suitable for purchasing for specified uses, but rather they are selected to stimulate visitors and provide them with a chance to experience new developments in materials. Some of the materials are one-off pieces by artists or designers, whilst others are samples from research and development laboratories and others are just inspiring and unusual items that have been recently launched into the marketplace. None of these samples are available for people to take away, but the producers' contact details are provided.

Material Lab also houses a 'Reference' section containing books on materials and design, bound swatches and literature on the samples provided by manufactures. Visitors are free to browse these shelves and compile a dossier of information that pertains to the samples and areas of material interest that they are sourcing. Visitors range from commercial and industrial design teams, to student groups and casual passers-by, with each user coming to the space with a different purpose and gaze. With this in mind, Materials Lab have a number of spaces downstairs from the showroom that they hire out for a variety of activities, from product launches and private views to meetings and creative 'brain-storming' sessions. The website (www.material-lab.co.uk) is little more than a holding page, offering links to sponsors, a minimal description of the contents of Materials Lab and the address and opening times of the showroom.

2.3.2 Professional Resources

For the purposes of this report the professional resource is defined as a materials collection that is constructed for the use of a particular profession, within its own environment, that rarely looks beyond their professional remit when gathering and selecting samples. It is within these libraries that the presence of 'materials products' can be strongly felt as the collection stands as a declaration of possible, certified and usable material options that can be specified, sourced and purchased to service the needs of a particular job. The number of these libraries is difficult to define for they are by nature private and for the exclusive advantage of their employees and those connected to projects they are working on. On the whole, very little information on the nature of these libraries exists in the public domain, but a few examples are given below.

The IDEO Tech Box

The California based consultancy firm IDEO specialise in design innovation for multinational companies. As part of their process of applying innovation, IDEO employ a number of strategic tools to maximise their creative thinking. One such tool is the 'Tech Box' which acts as IDEO's "knowledge-sharing library", allowing IDEO to archive experiences "gained from work across many industries and share it across all studios in our worldwide network" (IDEO, 2007). Although the Tech Box is intrinsic to the commercial 'innovation service' offered by IDEO, it is in effect a private professional resource.

The box itself (as shown in figure 2.12) contains several drawers holding hundreds of objects, from smart fabrics to elegant mechanisms to clever toys, each of which are tagged and

Figure 2.12: The IDEO Tech Box, as illustrated on their website (IDEO, 2009).

numbered (IDEO, 2007). Users are encouraged to "rummage through the compartments, play with the items, and apply materials used by other designers and engineers within the company to their current project"(IDEO, 2007), enabling in-house knowledge to be maintained, used and advanced, whilst maintaining a feeling of active discovery. Apart form the physical existence of the Tech Box, its entire contents are available on the company's intranet "through a searchable website, with each item listing its specifications, including manufacturer and price, and an additional IDEO anecdote with designer and project info if applicable" (IDEO, 2007). Employees are prompted to use the Tech Box and the internet site as a source of inspiration, as well as the focus of formal brain-storming sessions and problem-solving enquiries. All of the major IDEO offices have a Tech Box curator who "oversees the addition of new materials, and most IDEO employees are constantly on the lookout for likely candidates for addition" (IDEO, 2007), demonstrating the commitment of IDEO to the upkeep of the resource and the way in which the expansion of the knowledge that it contains is directly linked to the activities of the firm.

The Architectural Practice

The firm Yorke, Rosenberg & Marshall embrace the practice of 'hotdesking'[10] which actively prevents the accumulation of materials samples by staff, for at the end of each week they are expected to clear desks, leaving no trace of the collection of material ephemera. Figure 2.13 shows the 'hotdesk' studio space of Yorke, Rosenberg & Marshall; free from clutter and materials objet

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[10] 'Hotdesking' is the workplace practice of not assigning a worker their own desk but allowing the staff to use space in a flexible manner, sharing surfaces and areas depending on the needs of the moment.

d'art. Whilst this does provide a clear and well organised working environment, it also means that it is difficult for someone who may be doing a project using wood, for example, to have samples of relevant woods with them as they work. This situation highlights the need for a practice-centred materials resource, which archives and preserves materials, allowing them to be present during the devising, creating and specifying processes.

Figure 2.13: The 'hotdesking' environment inside Yorke, Rosenberg & Marshall; an architectural, planning and design practice.

Fosters and Partners have understood the need for, and opportunities presented by, a formal materials library resource and have materials samples as part of the wider library collection within the practice. Open to anyone working in or for this architectural practice, the archive of books, videos, plans, models and materials, are overseen by a full-time librarian and curated for the needs of the users. If an architect specifically asks for literature on, or samples of, a material the librarian is charged with servicing this request. The permanent collection of materials within the library are largely of set dimensions and the majority of samples are suitable for architectural use. Similarly, Hellmuth, Obata and Kassabaum Architects employ a full time librarian to manage their materials resource; a resource that only contains samples of materials that are approved for use in construction in some way. This results in a collection that is accessed by the architects with a view to being a service for linking architects with manufacturers and finding materials solutions to design problems.

The Institute of Materials, Minerals and Mining

Since the work of this thesis began, a new materials library was established by The Institute of Materials, Minerals and Mining (IOM3) at their head quarters in London and was formally opened in September 2007. [11] The Materials Resource Centre (MRC), as it has been named by IOM3, forms part of their Materials Information Service (MIS) that strives "to help companies to select the appropriate materials and processes for their products" for "correct materials and process selection is fundamental to a product's success –get it right and profitability and product performance are maximised, but get it wrong and poor performance and product failure soon lead to a damaged reputation in the marketplace" (IOM3, 2008). Reference to "profitability", "products" and the "marketplace" reveal the thrust of the MIS's work as orientated to industry and commerces, with IOM3 positioning itself as an ally of business.

In 2006 the IOM3, as part of its Knowledge Transfer Network (KTN) initiative, established the Materials and Design Exchange (MADE) project to "bring together the communities of design and materials technology in order to stimulate innovation, promote the transfer of materials knowledge and improve the competitiveness of UK business" (MADE, 2009). Partners in MADE include the Design Council, the Royal College of Art, The Institution of Engineering Designers and the Engineering Employers Federation. Membership of MADE is free for individuals and simply requires the registering of a person's details and professional interests on their website (www.made.uk.net).

The MRC was created in order to further the work of both MADE and the IOM3's MIS, providing a resource that promoted the products of the material industries to design communities. Visiting the MRC is free to all MADE members, who can turn up unannounced between the hours of 9am and 5pm, Monday to Friday. Time spent in the MRC is not limited, nor is it supervised by any member of MRC staff. However, if a visitor wishes to meet with a material specialist at the MRC, appointments can be booked over the phone or by email. Groups of ten or more people are encouraged to contact the MRC before visiting and are offered the chance to be introduced to the collection at the start of their visit by one of the MRC staff (Bellara, 2009).

The MRC is curated by Dr Sumeet Bellara, a material scientist and engineer, who works as both a materials advisor for MIS and as a design technologist for MADE. As the curator he is responsible for the selection and presentation of materials within the MRC and is the first point of contact for visitors desiring a consultation whilst at the resource centre. Bellara is currently attempting to catalogue the collection.

The MRC is contained in a single room with 'mobile aisle' shelves (as shown in figure 2.14). Such systems enable a greater number of shelves to be present within the limited footprint of

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[11] The curatorial team of IOM3 sought advice and counsel building a materials library and the problems and issues that can arise with such collections from the author of this thesis in 2006 before developing their own methodology and style.

Figure 2.14: The central 'mobile aisle' shelving area of the IOM3 Materials Resource Centre.

a given room, for the shelves roll back and forth on casters along tracks in the floor. Visitors simply turn the handle at the end of each shelf to widen or contract an aisle, moving shelves apart or bringing them together. The configuration of such shelves means that widening one aisle inevitably narrows another, thus it is really only possible to have two or three aisles open for easy browsing at any one time. As a storage solution it is commonly found in academic archives and libraries where large amounts of written materials need to be stored but are not required to be constantly accessible.

In front of the visitor, just inside the door, is a comments book and ring-bound folder that contains a number of instructive pages that resemble Powerpoint slides, some of which are also to be found around the room in the form of instructive signs. The main thrust of the contents of this folder is to ask visitors to handle the materials with care and provide a list of contacts in case of emergency or query. One page of the folder (as shown in figure 2.15) offers a "simple key" to the collection and reveals that "the colour of the title text in each frame identifies the material type".

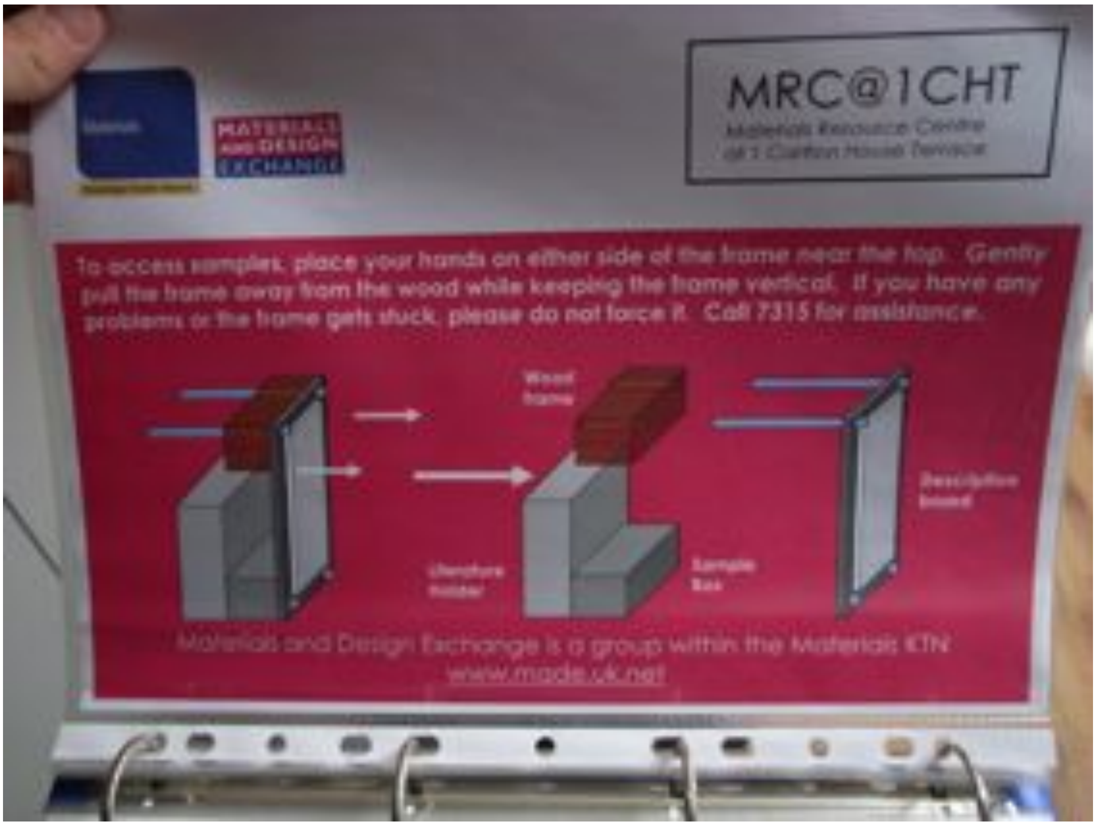
As figure 2.14 shows, each of the shelves contains row upon row of acrylic frames that present sheets of paper of uniform design and dimensions (A4). A sign, located at the end of each aisle, above the handle, reveals that the data sheets within the frames are "description boards" that one must remove to reveal the material within a "sample box". The sign also provides a graphical illustration of the construction of the display and gives instructions for accessing the materials and their literature that reside behind the description boards (see figure 2.16).

The photographs in figure 2.17 show the reality of this system as well as a close-up view of the description board for the material d3o ("dee-three-oh"). The board begins with the title "comfortable impact protection strain-rate dependant rubber" (in large red type) then proceeds with the following; "a material which will mould to the shape of your body and bend with it but stiffens to protect you from impact. It is available as a putty or in rubber

Figure 2.15: The "simple key" of the MRC that endeavours to show how the materials are colour coded within the collection according to type.

format. In the rubber form, it is available in sheets or in component form." This description focuses on the use for which it has been designed and thus the specified functionality of the material. The literature inside the "literature holder" states that "d3o is a specially engineered material made with intelligent molecules. They flow with you as you move but on shock lock together to absorb the impact energy" –going some way towards a scientific explanation of the material. The description sheet also informs the reader that 'd3o Lab' have "in-house facilitates for concept design, detailed CD/CAM, prototype tooling, real world testing, comparative testing and reporting and prototypes casting". This reiterates the role of the resource as a conduit between designers, specifiers, industry and product solutions. As can be seen in figure 2.17, the description sheet text is accompanied by two images, one of the material in its "rubber component type 1" format and the other of a suit that uses d3o as a protective layer. The far right-hand photograph in this figure shows a piece of d3o inside the "sample box". This sample is identical to the 'type 1' sample photographed and presented on the description board.

Bellara describes the MRC as "filled with shelves of small material and component samples in slots" with a capacity of 500 slots, though at present "240 slots are filled, each holding from



To access samples, place your hands on either side of the frame near the top. Gently pull the frame away from the wood while keeping the frame vertical. If you have any problems or the frame gets stuck, please do not force it. Call 7315 for assistance.

Materials and Design Exchange is a group within the Materials KTN
www.made.uk.net

Figure 2.16: The sign positioned at the end of every row of shelves in the MRC (also found in the ring-bound folder), illustrating how to access the material samples. The location of the "literature holder", "sample box" are indicated and shown to be behind the "description boards".

one to ten samples" (Bellara, 2009). Many of the samples are commercial or industrial in nature (hence the use of the term "component") and relate to the material manufacturing industries of the UK, although the MRC also make reference to one or two of their more esoteric samples on their website that states; "samples range from hemp fibres and paper made from recycled sheep's poo to flooring systems made from an aluminium honeycomb core sandwiched between glass skins and expanded PTFE vascular prostheses" (Bellara, 2009).

Some larger items that do not fit inside prescribed slots reside on a shelf that is not fully compartmentalised and can be found at the back of the shelf stack and seen in the right-hand photograph of figure 2.18. Such items range from a tennis racket and teflon pots and pans to extruded aluminium beams and rotationally moulded polycarbonate packaging. In the space adjacent to the shelves is a conference table around which even larger items are arranged. This space can be seen in the left hand photograph of figure 2.18. Amongst these larger samples are three car seats finished with different fabrics, a carbon fibre nose cone from a Formula One racing car and a suit of military body armour (as shown in the central photograph of figure

Figure 2.17: Far Left: A selection of the description sheets in their acrylic frames. Left: The d3o description sheet. Right: A view round the side of a partially removed acrylic pane. Far Right: The sample of d3o residing in its "sample box" along with some additional literature on the material.

2.18). These larger samples are all very much designed objects that have specific properties due to the material from which they are made, but exist in the MRC as objects of material interest that have a clear relationship to industry, manufacture and high-end material performance.

Figure 2.18: Left: The conference table located in the space adjacent to the mobile aisle shelving. Around this table, larger items such as car seats, a wheel chair and a large piece of carbon fibre are located. Centre: British Army body armour in No.5 desert combat camouflage, lent against the wall around the edge of the conference table space.

All of the material samples within the MRC are tagged so that if they were to pass through the security gates located at the entrance of the MRC, an alarm would sound. Such a system ensures that all materials remain in the collection and the resource does not need to be supervised. Signs remind users that "this display and all items in it have been secured using an alarm system" and that "for your safety and security CCTV is in operation throughout the building". The tag and alarm system is that used by many high street shops and libraries in a similar attempt to stop theft.

2.3.3 Institutional Collections

The Institutional Collection is one that belongs to an academic institution and primarily serves the needs of the student body. The type of courses an institution runs may effect the types of materials found in its collection and the focus of the information the resource provides. At a recent meeting of art educators at IOM3, materials libraries came under discussion and were "considered by many participants to be an extremely powerful resource for students" and delegates from institutions without materials libraries "all wished for one, or at least for access to such a facility" (Ward, 2008). The following section looks at the materials collections of three different Arts institutions.

California College of the Arts

California College of the Arts (CCA) houses its materials collection on the San Francisco campus in the New Materials Resource Centre. Formerly the New Materials Reference Library, the resource "offers a comprehensive, interdisciplinary collection of samples" (CCA, 2007) to all CCA students, staff, alumni and sample donors free of charge. Members of the public who wish to visit the resource must contact the collections archivist to make an appointment and discuss terms of remuneration. The resource was established in 1999 and has benefited from grants from the George Frederick Jewett Foundation totalling $75,000 that have enabled the creation of a sustainable and evolving materials centre.

The aim of the New Materials Resource Centre is to "inspire designers to focus on the materiality of things, rather than on obvious practical applications" and does this by providing unlimited access to over 1800 samples that have been archived and catalogued in a database that is "searchable by properties, usage or manufacturer", though this database is not available to non-networked users (CCA, 2007).

Central Saint Martin's College of Art and Design

The Materials and Products Collection of Central Saint Martin's (CSM) is located in the traditional library at the Southampton Row site in central London. It is a freely available resource for all staff, students and alumni members of The University of The Arts. Members of the public who wish to visit the collection either need to request access in writing to the librarian or, if they are part of a another academic institution, they can obtain a *SCONUL Research Extra* card[12] from their own library and use it to visit the CSM resources. The collection does

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[12] The Society of College, National and University Libraries (UK) is a cooperative venture between higher education libraries that allows standard access and limited borrowing to card holders

not have a high public profile and relies mainly upon word of mouth, serendipitous exploration and inter-institutional recommendations for publicity, with the CSM libraries web page only having the following description of the resource under its Special Collections banner; "Materials and Products Collection: A reference collection of printed and electronic information from manufacturers, and a collection of materials samples" (CSM, 2007).

The collection is at present not formally catalogued but where possible, literature and samples are arranged alphabetically. Panels upon which swatches are hung (see detail in figure 2.19), proved easy access to a wide variety of material samples. Rails of hangers suspending samples of fabrics and drawers labelled 'marble' 'stone' and 'slate' for example, contain larger samples and chunks of the stated materials. An area for the display of new acquisitions doubles as a discovery table where users can lay out an array of materials that interest them. A small collection of materials-related books are provided alongside computer terminals that provide live links to materials databases, supplier search engines and materials manufacturing details. The library also offers folders of literature relating to items within the collection that have been given to the college by manufacturers and suppliers.

Figure 2.19: A collection of swatches in Central Saint Martin's materials collection.

Every sample in the collection has a sticker on it that has the following information entered onto it: a description of the sample or its trade name, the manufacturer or supplier, the date on which it came into the collection, the category of material it belongs to and a yes/no statement on whether there is literature or a catalogue to accompany the sample. The librarian in charge of CSM's materials collection, Jane Holt, says that they endeavour "not to be precious about our materials" and understand that this is "a live and current resource". Although samples are not lent out by the library, access is not restricted or supervised and occasionally bits are "snipped off" by eager students.[13]

Weekly drop-in sessions are run by Jane Holt for any member of the student body. Within these sessions students are able to ask general questions about the materials collection and are given assistance with searching and sourcing. On a less regular but more formal basis, Materials Clinics are held within the library materials collection. At these occasions, materials consultant Margaret Pope[14] spends a day in the college meeting students who have made pre-arranged appointments to discuss their specific projects and their material needs.

The ethos of the materials collection is very much based upon inspiring and responding to the needs of the students. On a shelf underneath the wall of swatches a 'Suggestions Book' can be found, in which the students are encouraged to leave their name, the date of the entry, an inquiry or comment and their e-mail address. A variety of messages of thanks, feedback and requests can be found but the majority are statements along the lines of; "more leather samples please", "more netting of varying mesh size" and "what about zips!"[15].

Rematerialise

The Rematerialise materials collection of sustainable and eco-materials located in the School of 3D Design at Kingston University and was initiated by Jakki Dehn in 1994 as part of her research into the creation of new materials from waste products. In 1996 the research culminated in the formation of an exhibition of materials entitled *Re-Materialise* that showed in the Royal College of Art before touring the United Kingdom. Exhibits from this then formed the basis of the permanent Rematerialise collection of today. Being situated within an academic institution, interested students potentially have access to the collection but the level of access is dependent upon the activities of Rematerialise and whether or not the materials are being prepared for, or are out in, a touring show. For the general public and design communities at large, visits to the physical archive are by appointment only and also subject to the same variables of content.

The Rematerialise project has a well-defined materials focus, striving to provide a "carefully researched collection of greener material alternatives in a digestible and usable format... compiling and mediating its findings to the international design professions(s)" (Chapman and Dehan, 2006). As part of the development of this initiative, Jonathan Chapman joined the project in 2000 as Research Assistant and was responsible for the development of the Rematerialise web-

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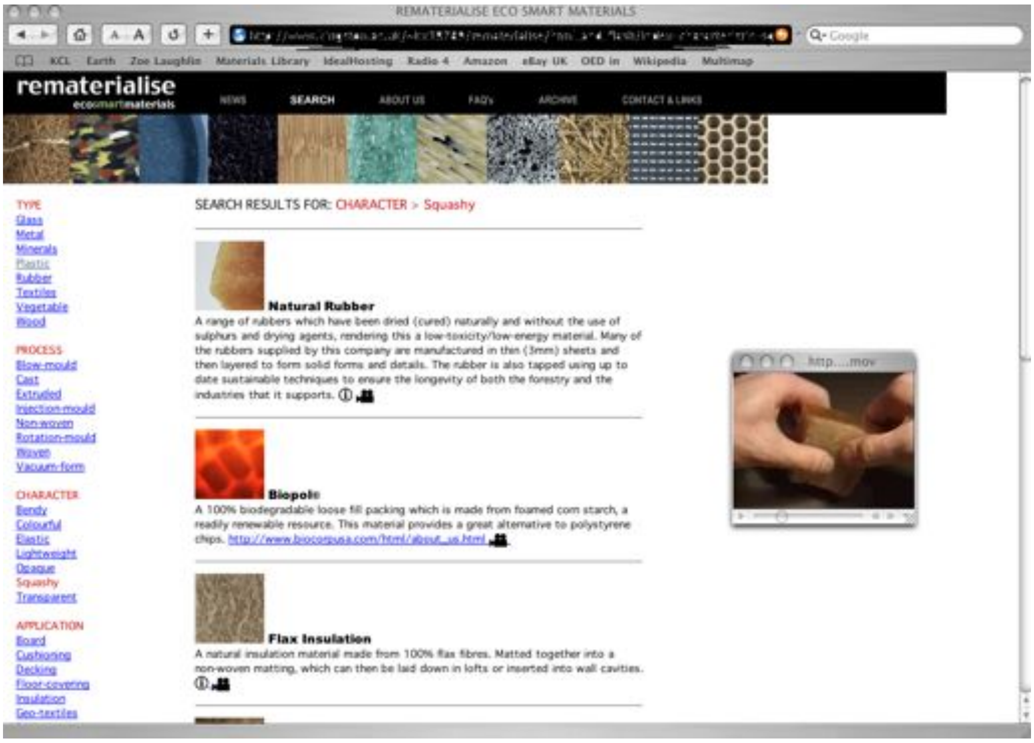
[13] Jane Holt in conversation with Zoe Laughlin, June 2006

[14] Margaret Pope was the person originally charged with setting up the CSM materials collection. She was also responsible for establishing the Royal College of Art collection which has since fallen into disrepair, though efforts for its revival are being made.

[15] Quotations gathered from within the Suggestions Book, June 2006

site. His input has meant that the physical archive of materials found a digital form and can be explored on-line by anyone with internet access. The funding for this project, however, was limited, meaning that the digital archive contains around 400 samples, whereas the physical collection has now grown to nearer 800.



SEARCH RESULTS FOR: CHARACTER > Squashy

Natural Rubber
A range of rubbers which have been dried (cured) naturally and without the use of sulphurs and drying agents, rendering this a low-toxicity/low-energy material. Many of the rubbers supplied by this company are manufactured in thin (3mm) sheets and then layered to form solid forms and details. The rubber is also tapped using up to date sustainable techniques to ensure the longevity of both the forestry and the industries that it supports. ⓘ

Biopol®
A 100% biodegradable loose fill packing which is made from foamed corn starch, a readily renewable resource. This material provides a great alternative to polystyrene chips. http://www.biocorpusa.com/html/about_us.html

Flax Insulation
A natural insulation material made from 100% flax fibres. Matted together into a non-woven matting, which can then be laid down in lofts or inserted into wall cavities. ⓘ

Figure 2.20: Viewing the video clip of natural rubber ‘in action’ on www.rematerialise.org

As well as sections outlining the background and mission of Rematerialise, the website offers the opportunity to search the materials collection. The user is invited to explore the “extensive database of ‘sustainable’ materials” that they state “represents the culmination of over a decade’s intensive research which has spanned the globe to pull together a diverse array of material information” (Chapman and Dehan, 2006). The search is streamed into four paths (Type, Process, Character, Application), offering a number of routes into the database, providing the user with “a way you can get to what you want, whilst finding a few surprises along the way” (Chapman and Dehan, 2006). Each route is then subdivided into more specific options, for example, ‘glass’, ‘metals’ and ‘plastic’ under the Type banner, and ‘cushioning’, ‘insulation’ and ‘paving’ under the Applications banner. By doing this, the Rematerialse project “hope to present the collection as a creative tool in itself” (Chapman and Dehan, 2006) where materials can be explored and discovered without the need to know a great deal about them before starting. Once the user has located a material of interest on the site, they can click to gain access to images, contact information of suppliers and in some cases, watch QuickTime™movies of the "material in action" (Chapman and Dehan, 2006). A clip available for the natural rubber sample shows a pair of hands manipulating the material in a number of directions and applying to it twists, turns, pulls, bends and compression. Figure 2.20 is a screen shot of what is seen in the web browser at this point in the exploration, with the QuickTime™window popping up in the centre right of the screen. This is currently a unique feature of the site, that advances the user's perception of the materials beyond the written description and often abstracted still image, bringing the human-scale and modes of play to bear on the materials knowledge presented.

2.3.4 Synthesis

To summarise, ten different materials resources have been identified in this section, four of which are commercial ventures, three are professional resource, and a further three are materials libraries currently based in educational institutions. Each boasts a unique collection of materials and places at the heart of its methodology the opportunity to touch, interact and experience real samples of materials. Each presents varying models of accessibility to users from a range of material communities: from professional product designers who pay a subscription to Material ConneXion (section 2.3.1), to fashion design students studying at Central Saint Martin's College of Art and Design who have free access to their college library (section 2.3.3), and architects constructing a private palette of materials that relate to specific projects (section 2.3.2).

In the case of commercial ventures in particular, the currency of the resource is often enhanced by the presence of a virtual database that provides a way of searching the catalogue, using pre-selected descriptors that can refer to a material's scientific properties, mechanical behaviours and qualitative attributes. The value of such a database lies not only in its use as a tool for materials selection, but in the fact that it can be accessed by users not at the physical location of the collection, thus giving a virtual version of the materials library to clients who are unable to attend the physical space.

Types of samples presented in the materials libraries range from commercial swatches and examples of materials provided by manufacturers, to found objects representative of a specific material's use, though the majority of collections favour the former. The vast majority of all samples within all of the materials libraries are materials that can be sourced for use, with little or no space is given to unique items, samples that are not available for procurement through a known third party, or materials that have failed in some way or other and cannot be purchased.

The question of how to represent materials science for the non-scientific user is, if addressed at all, approached in a literary or numerical manner rather than an experiential one. The more technical aspects of materials knowledge have yet to be interpreted and represented through the physical collection of a materials library in a manner that embraces the physical experiencing of such properties. Materials libraries are ever increasingly in demand from a wide range of practitioners who have a need to physically encounter materials to inform, excite and inspire their work: to gain inspiration from and an insight into materials. Many of these practitioners do not have the formal background in materials necessary to access scientific and technical knowledge by interpreting data sets or technical textbook descriptions. As a result, the question of how such resources curate and communicate their content will be an ever increasing issue. The programme of work presented in this thesis attempts to address how materials themselves can be used in the context of a materials library to represent aspects of material science and to this end, how the operational and performative relationship between materials and objects could be explored.

Chapter 3

Approaching Objects

This chapter introduces a theory of objects as relevant to the work of materials libraries and establishes the notion of a material-object continuum. The trope of the swatch is explored as a common mode of material sample presentation and the potential for the creation of new types of swatches is identified. The idea of the 'materials encounter' is also established in this chapter as being key to the operation of a materials library. Finally a set of experiments are proposed to test the theory explored in this chapter, the descriptions of which follow in chapters 5, 6, 7, 8 and 9.

> **object • n. 1** a material thing that can be seen and touched. ► *Philosophy*; a thing external to the thinking mind or subject. –ORIGIN ME: from med. L. *objectum* "thing presented to the mind'. (OED, 1999)

Materials libraries exist without direct definition of materials but through the exhibiting of the *stuff* of matter, defining themselves through a particular relationship to objects –that of the appreciation of their materiality. Be it through the inclusion of swatches of industry standard building materials or collections of disposable cups, samples within a materials library can all be viewed in relation to their object nature, as "a material thing that can be seen and touched" (OED, 1999). Therefore, it is pertinent to examine an element of the discourse of object theory, in order to ascertain how an approach to objects might inform a materials library.

3.1 A Theory of Objects

In *Capital* (1867), Karl Marx outlines the relationship between the capitalist economy and objects through a critique of the object as commodity.

> It is absolutely clear that, by his activity, man changes the forms of the materials of nature in such a way as to make them useful to him. The form of wood, for instance, is altered if a table is made out of it. Nevertheless the table continues to be wood, an ordinary, sensuous thing. But as soon as it emerges as a commodity, it changes into a thing which transcends sensuousness. (Marx, 1990, p163)

Marx suggests that as such transcending commodities, objects acquire a fetish status that derive their power from the monetary value for which they stand rather than the sensations they provide or the use that they serve. His discourse states that "the *use-value* of material objects belongs to them independently of their material properties, while their *value*, on the other hand, forms part of them as objects" and "the use-value of a thing is realised without exchange" whilst "inversely, its value is realised only in exchange" (Marx, 1990, p177). This differentiation between the value and the use-value of an item demonstrates Marx's appreciation of the creation of objects through the manipulation of materials relative to designed function and proposed use rather than through their status as tradable commodities of abstracted and fetishised value.

For Marx, the fetishised commodity, be it in the form of object or material, is valued as a product to be bought and sold, in a way that no longer ascribes value in relation to modes or processes of labour and production. In a capitalist system of mechanised and industrialised production, Marx claims the producer is divorced from the user and the user similarly detached from the maker in a way that alters the sociability of objects and their makers, masking "material relations between persons and social relations between things" (Marx, 1990, p166). The result of this is that for the consumer, objects simply appear, ready-made, miraculous and complete upon shelves with a stated "exchange-value", rather than emerging through a more direct system of labour where an object is negotiated into being by maker and user with a clear and dynamic "use-value" ascribed (Marx, 1990, p177).

In an attempt to arrive at a discourse for objects within society, Jean Baudrillard, in his book *The System of Objects* (1968), addresses objects from a sociological and semiological point of view, foregrounding the object's value as *sign*. He clearly states that he will not be concerned with "objects as defined by their functions or by the categories into which they might be subdivided for analytical purpose" or in other words, a formal scientific attempt at objective classification, "but instead with the processes whereby people relate to them [objects] and with the systems of human behaviour and relationships that result there from" (Baudrillard, 2005, p2). With this in mind, his enquiry focuses on the domestic 'everyday' encountering of objects, exploring the role of the object as meaning-maker, acknowledging the place of this meaning within the socio-political nexus of Marx's capitalist economy. He argues that through purchasing things, we are purchasing status and that the nuances of the form, function, material, or model of these things are the primary signifiers of this status and therefore lie at the heart of the social and cultural functioning of societies.

Running throughout *The System of Objects* is an acknowledgement of the materiality of objects and the significance of materials when extrapolating meaning from objects. When discussing 'Atmospheric Values', Baudrillard focuses on the influence of materials and declares that "objectively, substances are simply what they are: there is no such thing as a true or a false, a natural or an artificial substance" (Baudrillard, 2005, p39). This metaphysics underpins Baudrillards assertion that the binary values of properties (natural = true Vs. artificial = false) are socially constructed rather than inherently contained within matter as scientific fact. He states that "we apprehend old synthetic materials such as paper as all together natural", with"the inherent nobility of a given material" existing "only for a cultural ideology" (Baudrillard, 2005, p39), demonstrating that the material status of paper is simply the result of cultural forces and connotations. Furthermore, whilst acknowledging that "substances are simply what they are", Baudrillard sees the fundamental abstract nature of matter as that which makes possible both the physical and semiotic construction of objects (Baudrillard, 2005, p39). For example, Baudrillard states that "an exposed ceiling beam is every bit as abstract as a chrome-plated tube" and that it is simply cultural systems that differentiate combinations and assign value, for "what nostalgia paints as an authentic whole object is still nothing but a combining variant"(Baudrillard, 2005, p41).

As part of his analysis of the object, Baudrillard offers discussion on form and function. Beyond simply the shape of an object, he sets out that forms must be considered as "relative to one another, and continually refer to other homologous forms" (Baudrillard, 2005, p42). In other words, no form can stand outside of the networks of forms and each form is in constant negotiation with others as to its nature. Function is inextricably linked to form in the terrain of the object, as the form something has is often a direct response to serving function: as if, in the operational equation of The Object, Form and Function are functions of one another, feeding off and into each other simultaneously. Within the arena of function alone however, there is a difference between 'vulgar' objects, "objects that are nothing more than their function"(Baudrillard, 2005, p69), and those objects with high 'functionality' where "the object fulfils itself in the precision of its relationship to the real world and to human needs" (Baudrillard, 2005, p67). It is key that functionality relates to the object's "ability to become integrated into an overall scheme" (Baudrillard, 2005, p67) for this not only addresses the use of the object, the needs of the user and the desires for function, but allows space for the recognition of the schema of meanings and significations that belong to objects. For Baudrillard, "an object's functionality is the very thing that enables it to transcend its main 'function' in the direction of a secondary one, to play a part, to become a combining element, an adjustable item, within the universal system of signs" (Baudrillard, 2005, p67).

Susan Leigh Star and James R. Griesemer established the concept of *boundary objects* that embrace multiple functionality and display an "ability to become integrated into an overall scheme" (Baudrillard, 2005, p67) for they establish boundary objects as those objects "both adaptable to different viewpoints and robust enough to maintain identity across them" (Star and Griesemer, 1989, p387). Their 1989 paper *Institutional Ecology, 'Translation' and Boundary Objects* contains a study of the ways in which a variety of practitioners collaborated to establish the Berkeley Museum of Vertebrate Zoology in California, between the years of 1907 and 1939. The practitioners involved ranged from hunters and taxidermists, to amateur naturalists and professional biologists, with all engaged in the mission to preserve "a vanishing nature", and to make a record "of that which was disappearing under the advancement of civilisation"(Star and Griesemer, 1989, p401). Star and Griesemer state that the varying methodologies and theoretical frameworks of each practitioner were potentially problematic. Procedures, facts and methods considered vital to one person may be completely overlooked by another and therefore vital information lost. This problem was tackled however by "the creation and management of boundary objects", a process that was key to "developing and maintaining coherence across intersecting social worlds" (Star and Griesemer, 1989, p393). Star and Griesemer site "specimens, field notes, museums and maps of particular territories" as examples of the types of objects called upon to become boundary objects, "inhabiting several different social worlds and satisfying the informational requirements of each" (Star and Griesemer, 1989, p408 & 393).

The ability for specimens, field notes, museums and maps to be "simultaneously concrete and abstract, specific and general, conventionalised and customised"(Star and Griesemer, 1989, p408) lies at he heart of their boundary nature. Star and Griesemer offer four types of boundary objects in an attempt to arrive at a system of analysis, rather than a mode of division. Two of these types are of particular relevance to a materials library and the items found within it. First is the boundary object as *repository*. "These are 'piles' of objects which are indexed in a standardised fashion", inferring methods of categorising cataloguing, labelling and arranging, with the direct example of a repository boundary object given as "a library or museum", where people from varied and different worlds "borrow from the 'pile' for their own purposes without having directly to negotiate differences in purpose" (Star and Griesemer, 1989, p410). The second relevant type of boundary object presented is the *ideal type*. An example of an ideal type is a species, for; "this is a concept which in fact described no specimen, which incorporated both concrete and theoretical data and which served as a means of communicating across both worlds" (Star and Griesemer, 1989, p410). In this case the boundary object operates in the territory staked out by the concept, with differences between them arising in the "degree of abstraction" from the concept. (Star and Griesemer, 1989, p410)

3.2 The Material-Object Continuum

Science presents conceptual models of matter that predict behaviours and properties. As previously discussed in section 2.1, the Periodic Table is a map of these concepts and is central to the modelling of materials. Taking copper as an example, one can locate the element on the Periodic table and infer from this the configuration of the protons, neutrons and electrons of a copper atom. From this, valence results and the prediction of properties become possible. The high electrical conductivity of copper, for example, is a direct result of the number of free electrons present in the conductivity band of a lattice of copper atoms. Therefore the ability of copper to behave as an electrical conductor is a direct result of the properties of its atoms; its performativity is engendering the expression of properties. This scientific model of copper enables acts of classification, both of things as copper and other things being like, or similar in some regard, to copper (ie: metals). Rather like the concept of species for Star and Griesemer, the concept of the material offers a model of the "ideal type" which "incorporated both concrete and theoretical data and which served as a means of communicating" information about the properties of the material (Star and Griesemer, 1989, p410).

Once something exists, it can be seen as stepping away from the concept of the material and towards the idea of the object, or visa versa; embracing notions of form and function (as established by Baudrillard) in relation to embedded materiality, and thus becoming a *material-object*, existing within the nexus of all possible material-objects on a material-object continuum. 'Material' and 'object' are purposely hyphenated here to propose an evaluation of the status of each as being continually linked to the other. There is no matter without a form and no object without material. The hyphen also graphically suggests the continuum by drawing a line between the two words, placing each at the end of the linkage, presenting two pillars for the theory of a materials library.

The proposition of the idea of a continuum offers the following possibility: that materials

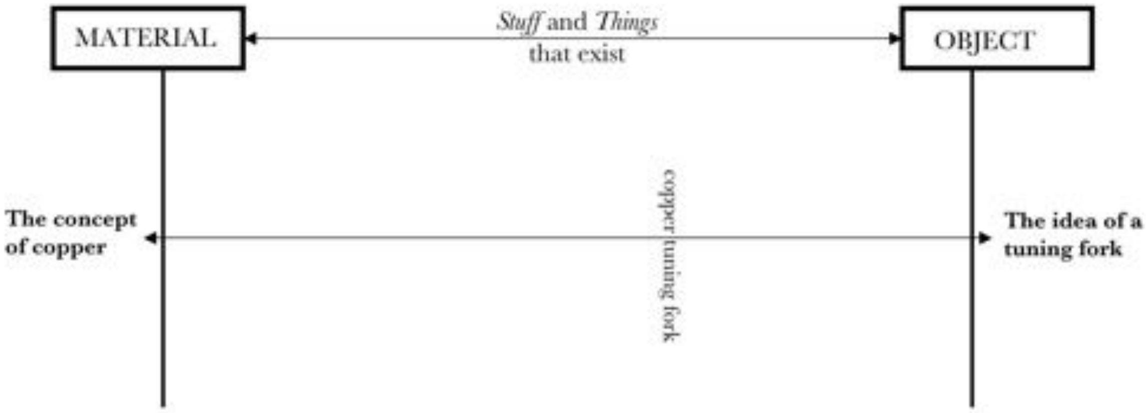


Figure 3.1: The material-object continuum, in relation to the copper tuning fork.

are abstract entities, theoretical tools and conceptual models, and that objects are ideas of form and function. All *stuff* and *things* that exist therefore, fall along a material-object continuum, being either of a state of more-or-less object, or more-or-less material, but can never be totally material or totally object, for this returns the *stuff* or *thing* to concept. Figure 3.1 illustrates a basic material-object continuum. The nexus of material-objects is represented in figure 3.2 with each node of the network representing a possible material-object. The figure maps the territory of operation of a materials library; for in acquiring, displaying and demonstrating *stuff* and *things* in order to foreground materiality, a materials library becomes the domain of the material-object, rendering physical the continuum, in turn placing the material-object at the heart of a theory of a materials library.

3.3 Beyond the Swatch

> **swatch** • **n.** **1** a piece of fabric used as a sample. ▶ a number of these bound together. **2** a patch or area. –ORIGIN C16: orig. Scots and north England, of unknown origin. (OED, 1999)

The concept of the swatch is one familiar to many involved with the generation, procurement and use of material samples, be it from the point of view of industries and manufacturers, designers and makers, or those charged with the curation of a materials library. Traditionally, a swatch referred to pieces of fabric of uniform size, bound together to make a book of samples (OED, 1999). Such swatches can still be found in haberdashery stores, carpet warehouses, and

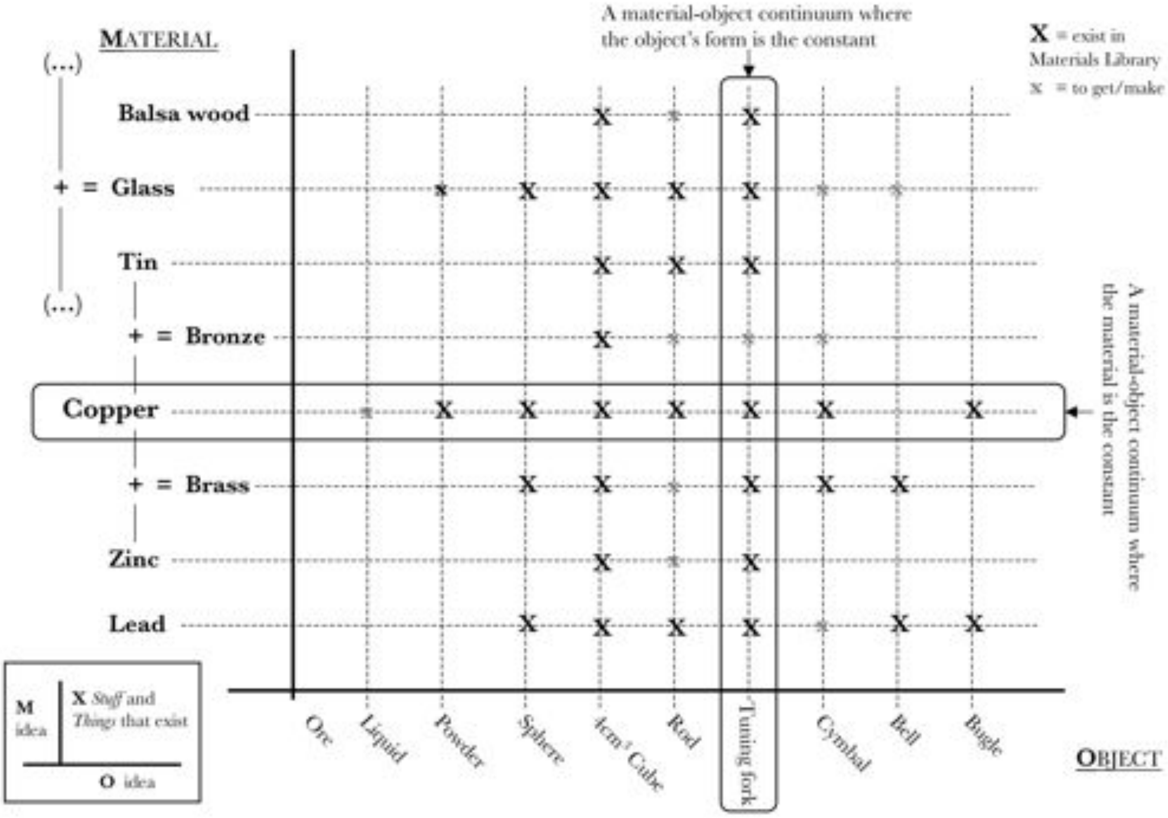


Figure 3.2: The nexus of material-objects, shown as the *stuff* and *things* that exist within the axes of the concepts of matter and object on the material-object continuum.

tailor's shops. Developing on from this use, the term 'swatch' has come to embrace samples of any number of materials in sheet form that are presented in a uniform size, bound together by virtue of a chain, ring, string or other mode of fastening. A graphic representation of a typical material swatch can be seen in figure 3.3

Both materials suppliers and users find swatches useful and efficient reference objects and a way of communicating and discovering the range of material products available. In such a way, the swatch is a form of "boundary object", moving between communities, "inhabiting several different social worlds and satisfying the informational requirements of each" (Star and Griesemer, 1989, p408 & 393). The Materials Lab, as introduced in chapter 2 section 2.3.1, is an example of a swatch based methodology (samples of uniform dimensions) being used to create a form of materials library that aims to communicate a range of products available from a specific manufacturer. The walls are lined with shelves displaying row upon row of tiles of equal dimensions, turning the space itself into a giant swatch within which the user walks and explores. Specially designed cardboard boxes are offered to visitors who wish to take away a few of the tiles that specifically interest them. The box can hold a maximum of 10 tiles and enables

Figure 3.3: An archetypal swatch of material samples. Each material is presented in a standardised form and bound together on a chain.

visitors to create their own swatch from the greater collection which they are free to take away with them.

The ability of the swatch to serve as a materials selection tool can be clearly seen in the case of domestic wall paint where swatches are ubiquitously produced by the paint manufacturers and offered to the public as the first point of contact with the available colours. The standard rainbow arrangement of the colours within a paint swatch enables users to access ranges of colours and easily compare the differences between hues and tones. The use of a swivel fastening mechanism allows the user to fan out specific colours and generate their own collections of selected colours than can be held up against surfaces or objects to see how the colours 'go' together. A graphic representation of just such a swatch can be seen in figure 3.4.

If someone wishes to paint the walls of their house, they may first select a number of colours by using a swatch and then acquire small sample pots of each colour before testing them on their walls in areas of shadow and direct sunlight. In doing so they can get a feel for how each paint responds to different lighting conditions. Painting such sample areas with the actual paint enables the user to create an area of the colour larger than that afforded by the swatch. Users recognise that scale is an important factor in the perception of the colour they select; an area of a colour they liked in the swatch book may appear too intense when viewed covering a larger area.

The acknowledgement of the effects of scale on the perceived properties of a material is

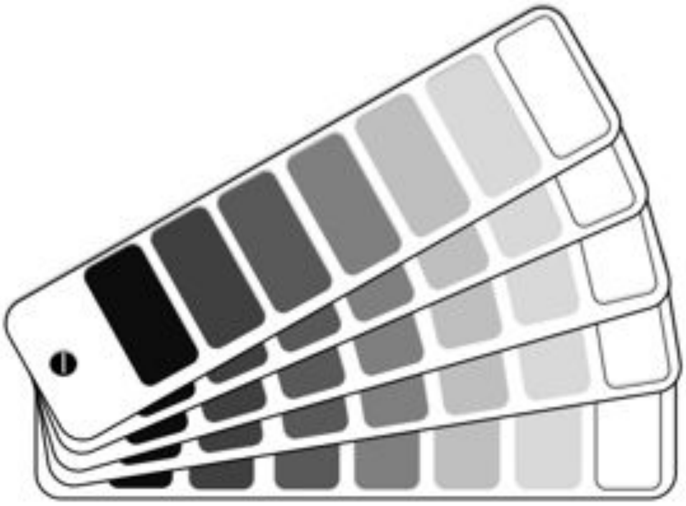


Figure 3.4: A fan style swatch with a swivel fastening, used for the presentation and communication of available colour ranges by companies like Pantone™, RAL™and Dulux™.

something not so commonly recognised by those producing material swatches. The majority of samples within a swatch are similar in size to a credit card, making the swatch an efficient hand-held object, able to be posted, carried and thumbed through easily. However, a swatch this size may limit the user's experience of a number of characteristics and properties of the material and does by no means fully represent the possibilities a material may afford an object.[1]

Whilst acknowledging the role of swatches as tools of materials communication and specification it is important to understand their limitations in terms of their relationship to objects and their users. As an object, a swatch encourages a degree of fetishisation on the part of the user. Its engagement with the materials selection process and link to the materials manufacturers places it in a position of power. Being supplied by manufacturers, often not free of charge, it is a formal material sample, official, officious and exacting. Desired and dealt with as a tool of apparent materials communication and inspiration, it is often an object coveted by users and flaunted by manufacturers at the meeting point of the trade fair. The swatch is the ultimate commodity for material specifiers; a product in and of itself, that professes to aid the materials selection process. It does not however speak of a material's relationship to functionality, foregrounding the role a material can play in the operative function of an object.

Acting as an exemplar of material possibilities and combinations, the swatch enables ready appreciation of material difference in relation to material properties such as appearance, finish

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[1] An exploration of the effect of scale on the perception and experience of a material in swatch form has been outlined in chapter 9, section 9.3.1, where the creation of a swatch of "the shiniest aluminium" presented samples of the material in sizes ranging from A7 up to A0.

and texture. The depth of material understanding that can be achieved with such an object is questionable but the format is such a strong signifier of material exploration that one cannot disregard the trope of the swatch as a mode of materials investigation. The question remains however, whether other types of swatches could be created that bring the structural phenomena and behaviours of materials into focus.

> **isometric • adj. 1** of or having equal dimensions **2.** Mathematics (of a transformation) without change of shape or size. –ORIGIN C19: from Gk *isometria* 'equality of measure' (from *isos* 'equal' + *-metria* 'measuring').
>
> **isomorphic • adj. 1** corresponding or similar in form or relations. (OED, 1999)

The isometric nature of a standard swatch enables the form of the samples to be, in effect, disregarded as the focus of the user's attention is on the materials used rather than on the form into which it is shaped, for it is the material (or some material property) that is seen to change. However, the effect the form of an object has upon the perception and understanding of a material is central to the recognition of the material-object continuum and the creation of the Materials Library. One way of paying more attention to the form and its relationship to function and materiality would be to use more explicit objects as the forms that are then given the swatch treatment –duplicated in a variety of materials to create a set of items bound together by virtue of their dimensional similarity. Consider an object like a chair. Keeping its form constant but replicating it in a variety of materials highlights that a chair's performance is inextricably linked to the material it is made out of. Whilst still adhering to the recognised form of a chair, a low density foam chair would cease to function as a chair as a direct result of it material properties.

> **set • n. 1** a group or collection of things belonging or used together or resembling one another. ▶ Mathematics & Logic a collection of distinct entities regarded as a unit, being either individually specified or (more usually) satisfying specific conditions. **adj. 1** fixed or arranged in advance. –ORIGIN ME: orig. partly from OFr. *sette*, from L. *secta* '*sect*', partly from OE *settan.* (OED, 1999)

Is it possible to create a materials library that explores, expands and explodes the trope of the swatch? That generates and collates *sets* of material-objects that enable materials within the sets to form relationships with each other, and those material-objects outside of the set? To make swatches that recognise the multifaceted nature of materials and understand that which is, and is not, represented by the form and its relationship to materials properties? The following three experimental chapters explore the possibility of going beyond the recognised mode of the swatch, where the isometric set of individual samples have equal dimensions and are bound together in their mode of presentation, towards an alternative territory of material-object curation where an isometric language becomes an isomorphic principle of set exploration. In doing so I expand upon the role of the swatch within a materials library in a way that acknowledges the multifaceted nature of material-object and renders physical the material-object continuum.

3.4 Towards an Encounter

A defining aspect of many materials libraries is the facilitation of touch. Unlike in a museum, the visitor or user is allowed, if not positively encouraged, to touch and physically experience the materials provided. Such 'coming together' of person and material lies at the heart of the notion of a material *encounter*. Within the context of the Materials Library space or an external event, the encounter is the meeting of person and material-object. It is a live physical experience that informs processes of material investigation, negotiation and appreciation. To pick up a slice of cake and eat it is a form of materials encounter; an encounter that can be altered by the addition of a fork but still classified as an encounter, this time between the cake, the fork and the eater.

> **encounter • v.** unexpectedly meet or be faced with. **1** an unexpected or casual meeting. **2** a confrontation or unpleasant struggle. –ORIGIN ME: from OFr. *encountrer* (v.), *encontre* (n.), based on L. *in–* 'in' + *contra* 'against'. (OED, 1999)

The deployment of the term *encounter* to describe the framed coming-together of materials and people, aims to underline the role of the unexpected in such a meeting and the possibility of a confronting experience. Confrontation should be considered here in terms of an arrestment of the senses, a moment that makes one notice, realise or consider something outside of the usual. A moment or scenario where an unexpected occurrence, discovery or experience punctuates our existence and results in a conscious noticing of matter.

Each person who engages in an encounter with a material will have their own style of doing so that embraces their personal desires, inhibitions, knowledge base, sensitivities and perceptions. Each of these will clearly affect the way in which a visitor will encounter a material but one must not disregard the role of the material-object in affecting the encounter. The material-object itself can lend itself to particular modes of investigation that afford particular types of encounter as a result of its scale, shape, properties and behaviours. Continuing the example of the material of cake, it is likely that encountering cake will involve eating, or at least the tasting of it. In doing so, cake is brought into contact with the mouth in a way that non-edible materials may not be. Cake, as both a material and as an object, is recognised and understood as edible, thus suitable for oral investigation. Other material-objects, like corn starch packaging pellets, are just as safe to eat but it is unlikely that people would eat them. The form and context of the material-object within the world at large suggest the material to be unsuitable for oral examination. However, cover something very similar in orange cheese flavouring and you have a popular cheesy puff snack. The form and properties of the corn starch packaging pellet may encourage an encounter that sees the squashing, tearing and compression of the material.

In his book *Relational Aesthetics*, Nicolas Bourriaud proposes the notion of relational art as art that understands, explores and acknowledges the broader relationships between the people and things that provide the context of the art experience. For Bourriaud, a relational aesthetic is one where the context becomes the material; an aesthetic that embraces “meetings, encounters, events, various types of collaboration between people, games, festivals, and places of conviviality, in a word, all manner of encounter and relational invention” as the aesthetic object, with a likelyhood that they should be regarded as such, “with pictures and sculptures regarded here merely as specific cases of a production of forms with something other than a simple aesthetic consumption in mind” (Bourriaud, 2002, p28-29).

The notion of encounter is central to a relational aesthetic: encounters between objects-and-objects, people-and-objects and people-and-people. For Bourriaud, an encounter could take the form of a physical experience, a conversation, or and situation but it primarily involves the construction of relations between all aspects present, be they object or human (Bourriaud, 2002, p47). If a work of art “remains around the edge of any definition: is it a sculpture? an installation? a performance? an example of social activism?” (Bourriaud, 2002, p25), it is more likely than not to be relational and embrace encounter as one of products of the work. The relational invites a sociability of object and materials, as well as “relations between individuals and groups, between the artist and the world, and, by way of transitivity, between the beholder and the world.” (Bourriaud, 2002, p26)

> In theatre and cinema there is no live comment made about what is seen (the discussion time is put off until after the show). At an exhibition, on the other hand, even when inert forms are involved, there is the possibility of an immediate discussion, in both senses of the term. I see and perceive, I comment, and I evolve in a unique space and time. Art is the place that produces a specific sociability. (Bourriaud, 2002, p16)

A materials library can also produce a specific sociability by facilitating the exhibition and encounter of material-objects. The notion of encounter for a material library thus becomes key to its relational operation, for a relational act must engender sociability between viewers and interactivity between viewers and material-objects. Bourriaud considers that which is made by the artist to be "a) moments of sociability" and "b) objects producing sociability" (Bourriaud, 2002, p33) and the same could be said for that which is made by the materials library. The materials encounter could be such a moment and materials-objects may produce such sociability between material, form, object, function, and people.

Within the notion of the materials encounter it is also important to acknowledge the invaluable role of the 'encounter facilitator' as host, librarian or *Materials Conjecturer* (explanation of this term is to come in section 9.3.1). This figure, in any instance of encounter, may stand back and observe or come forward and interject, listen to discussion and ask questions or recount stories and provide information in response to questions. In particular encounters, material-objects and participants will require handling in a variety of ways but the omnipresent guardian of the encounter enables relations to blossom. Bourriaud acknowledged as much when he wrote:

"Artists look for interlocutors. Because the public is always a somewhat unreal entity, artists will include this interlocutor in the production process itself. The sense of the work issues from the movement that links up the signs transmitted but the artist, as well as from the collaboration between people in the exhibition space." (Bourriaud, 2002, p81)

Bourriaud's interlocutors are involved behind the scenes of the art, sometimes working with the artist to produce the piece but always in a position of knowledge and are to be considered separate from the public as a result. In the same way, a materials conjecturer/librarian/expert/host often has a greater knowledge about the material and the proposed conjecture enabling them to provide links between the elements for and of encounter.

3.5 Proposed Experiments with Isomorphic Material-Objects

The following five chapters consider the nature of materials samples, through the experimental practice of material-object creation and the application of an isomorphic methodology where form is kept constant but material changes. In order to test the theory of material-objects and attempt to find forms that enable materials to demonstrate their properties and behaviours, the following chapters traverse the material-object continuum from the *cube* (chapter 5), to the *tuning fork* (chapter 6) and the *bell* (chapter 7), before arriving at the *spoon* (chapter 8).

Each set of material-objects combines to form a body of work that endeavours to go beyond the standard kind of material representation, towards a domain of isomorphic material-objects that explore the relationship between form, function and materiality. The journey through the chapters is designed to be one that moves from the abstracted material sample (a simple cube), to the highly functional cultural object (the spoon), in an attempt to explore the role of objects in materials libraries and the ability of these objects to represent particular aspects of materials science. In the final experimental chapter, the role of all these materials swatches is assessed within a wide variety of materials encounters (chapter 9).

3.6 Concluding Remarks

An appreciation of objects and the relationship between their form and their function has provided a backdrop for the establishment of a theory of material-objects, the notion of a material-object continuum and the perception of the nexus of possible material-objects that constitute a materials library. The trope of the swatch offers a way of providing form to matter in a manner that signifies and serves the selection of materials but does little to showcase other aspects of materials' properties and behaviours. To create sets of material-objects that use the methodology of the swatch, whilst exploring form and function, would enable exploration of the material-object continuum within the context of a materials library. If every object acts to censor the material from which it is made, is it possible to find forms that return agency to material, giving it a voice to speak and the means to display its properties and behaviours?

Much of the intention of the work has been to design and stage encounters with specific material-objects to explore whether the methodology of the swatch establishes parameters for the encounter that foreground materials' investigation and discovery. In other words, to test whether the arena of encounter could be a place where the use-value of a material-object can be explored as something both functional and imaginative, cultural and scientific, theoretical and actual; a place where matter can be appreciated and experienced as something other than a product for sale but as an agent for the advancement of conceptualisation.

Chapter 4

Methods

This chapter introduces the research methodologies that have been employed in this thesis to systematically interrogate both material-objects and audiences' responses and reactions to these material-objects, within designed instances of *encounter*. At the heart of this thesis is an interdisciplinary enquiry into the nature of materials and an appreciation of the broad spectrum of practices that celebrate the affordance of materials –the forms and functionality facilitated and enabled by the particular properties and behaviours of materials. Multiple and interdisciplinary methodologies have been developed in an attempt to investigate materials, and their representation, from both the point of view of the arts and sciences. The following outlines some of the schools of methodological thought that have influenced the design of the research into audience reactions and how information was gathered on the responses of people to the experiences presented.

4.1 An Overview of Relevant Research Methodologies

Materials can be interrogated by a number of different methods, each of which will reveal something of the nature of the materials, as well as the way in which different practitioners use different tools to gain knowledge about material behaviours and properties. In order to interrogate a rod of iron and consider how strong it is, one person may grasp it in their hands and attempt to bend it over their knee whilst another may place it in a specifically designed jig and apply a known load and measure the degree of deformation. Each reveals something about the material but also demonstrates something of the range of interrogative methods people apply to materials. In order to understand both the materials and peoples' interactions with them, this thesis draws upon a wide range of methodologies to systematically evaluate how the science of materials can be represented by the materials themselves, within the context of the experiential

Materials Library. What follows is an overview of the methodologies that have inspired this work and the field within which they are most commonly used.

4.1.1 Ethnography

Ethnography is primarily a social-sciences research method, predominantly employed by anthropologists and sociologists in an attempt to gather qualitative information about human cultures and behaviours. Ethnographic studies tend to focus their attention on three fundamental aspects of human experience: “what people do, what people know, and the things people make and use” (Russell-Bernard, 2002, p5). Originally associated with the study of ‘exotic’ non-western cultures, ethnographic studies were traditionally investigations into that which was seen as culturally ‘other’ and overtly outside of the western cultural hegemony. In the introduction to his 1922 paper, *Argonauts of the Western Pacific*, pioneering anthropologist Bronislaw Malinowski heralded the arrival of a “professional” and “scientific” ethnography that would elevate the study of other cultures through rigour and method (Malinowski, 1922). Papers like this and his later study *The Sexual Life of Savages in North-Western Melanesia* (Malinowski, 1929), are prime examples of the traditional ethnographic investigations into the lives and cultural practices of other cultures.

In recent years, ethnography has increasingly been used to examine the behaviours of people in the more everyday surroundings of the researcher’s own culture; from open plan offices (Heath and Pettinari, 1998) to art galleries (Heath and Lehn, 2004) and supermarkets (Miller, 1998). In essence, anthropology is “rediscovering otherness and difference within the cultures of the West” (Russell-Bernard, 2002, p23). The work of Daniel Miller in particular, firmly establishes ethnography as a tool for anthropologists to examine their own cultures, as if they were ‘other’, taking a fresh look at the practices and behaviours found on the British high street (Miller, 1998, 2001). As the subjects of ethnographic investigation broaden, the research methodology has been embraced in academic fields “where ‘culture’ is a newly problematic object of description and critique” (Russell-Bernard, 2002, p3). From applied arts to the communication of science, the “emergent interdisciplinary phenomenon” (Russell-Bernard, 2002) of ethnography is seeing the tools and rhetoric of the methodology embraced by researchers from a variety of backgrounds, joined together by their common interest in the behaviours, interactions and reactions of people (Clifford and Marcus, 1986; Miller, 1998; Meisner et al., 2007).

In most types of ethnographic study, empirical data is collected by the researcher through processes of observation, interviewing and recording the subjects, “provide[ing] the researcher with a way of becoming familiar with, and understanding, the world” from a particular standpoint (Heath and Pettinari, 1998). The act of gathering such data is termed 'field work' and references the studies of scientists who investigate subjects out in nature, rather than in the environment of the laboratory. "In conducting field observations, the researcher becomes immersed in a field site and systematically observes procedures and practices used by members in the setting, such as work practices, activities, interactions, workflow, etc." (Heath and Pettinari, 1998, p14).

The keeping of field notes is the primary tool used by ethnographers to record observations made whilst in the field (Burgess, 1984; Emerson et al., 1995). Although the style of field notes varies from researcher to researcher and project to project, field notes are characterised by the "jotting down key words and phrases", "quickly rendered scribbles about actions and dialogues" and "a word or two written at the moment or soon afterwards" to jog the memory (Emerson et al., 1995, p20). The notes gathered can then be written up to form a journal or log, or simply used in their raw form to gain an overall impression of events, occurrences and interactions.

Decisions of "when, where and how" field notes are taken is considered important in conducting an ethnographic study, for the act of taking notes can effect relations between researchers and subjects in the field (Burgess, 1984; Emerson et al., 1995; Davies, 2008). In openly writing notes and jotting down observations it is advised that "the fieldworker should act with sensitivity, trying to avoid detracting from or interfering with the ordinary relations and goings-on in the field" (Emerson et al., 1995, p22). In some instances of field observation however, the researcher's "participation in ongoing interaction may be so involving as to preclude taking breaks to write down jottings; in such instances, [s]he may have to rely upon memory, focusing on incidents and key phrases that will later trigger a fuller recollection of the event or scene" (Emerson et al., 1995, p23-24).

A desire to gather verifiable observational data of greater complexity than written field notes has meant that audio and video recorders have become increasingly common equipment for ethnographic filed workers (Heath and Pettinari, 1998; Davies, 2008). However, the use of such recording equipment presents issues of consent and ethics that often limit and inhibit their use (Heath and Pettinari, 1998). The scope of such technologies is also limited by the nature of that being recorded. For example, in scenarios that take place in a large area with multiple subjects, the ability of a fixed camera or microphone to record more than a simple overview is extremely limited. The presence of a roaming camera and microphone would transform the act of detached recording into active documentary film making, resulting in the gaze of the camera serving as an overt and possibly intrusive commentary on the subject, with all the issues of interpretation that lens based media invite (Sontag, 1978), as opposed to the status of 'outside eye' that the ethnographic filed worker strives to achieve (Spradley, 1980). Recording technologies are more readily used by ethnographic field workers in interview scenarios where the gathering of direct quotations is required but the researcher does not want to disturb the flow of the interview by taking written notes.

The interview is a key tool for ethnographic investigation and is commonly categorised in two ways; unstructured and semistructured. Unstructured interviews can be carried out in nearly any scenario and happen "just about anywhere –in homes, while walking along a road", as semistructured, or "in-depth" interviewing is a scheduled activity that is "open ended, but follows a general script and covers a list of topics" (Russell-Bernard, 2002, p203). It is important to remember that "different tyres of interviews produce different types of data that are useful for different types of research projects and appeal to different types of researchers" (Russell-Bernard, 2002, p204). Although this means that the field worker is free to select the method of interviewing that best suits them, the subject and the scenario, there are guidelines of best practice;

> "In situations where you won't get more than one chance to interview someone, semistructured interviewing is best. It has much of the freewheeling quality of unstructured interviewing and requires all the same skills, but semistructured interviewing is based on the use of an interview guide. This is a written list of questions and topics that need to be covered in a particular order." (Russell-Bernard, 2002, p205)

It must be stressed however that ethnography acknowledges that there are limits to how useful interviews can be for there is always information "that cannot be accessed by simply asking informants to discuss meanings and interpretations" of specific actions, events or objects (Davies, 2008, p51).

In all cases of ethnographic data gathering, be they written or recorded, the results of the utilised investigative methods provide the researcher with a body of evidence that can be repeatedly reviewed, analysed and studied in an attempt to gain a wider understanding of a specific event, sequence of interactions or set given of behaviours. The limitations of each method often call for multiple methods to be used in conjunction with a reflexive awareness of each, in a manner that understands that "in the strictest sense, the criterion of reliability is not applicable, in that no study is formally or perfectly repeatable" (Davies, 2008, p101). At this point, the central failing of ethnography as a social-*science* is revealed; in order for something to be scientific in its methodology, it is imperative that investigations and the results gathered be repeatable. This places ethnography, as a methodology, in a position of contrast with material science as a means of investigating the behaviours of materials. When considering the iterations of materials and people however, the observation driven approach of ethnographic field work does provide a way of considering the cultural dynamics of material-objects. Ethnographic tools could be of particular use when considering engagements with material-objects in dynamic scenarios that are not formal experiments and where broad trends of behaviours, and modes of interaction, can be observed.

4.1.2 Participatory Action Research

Within an ethnographic practice, the researching field worker often embeds themselves within the culture they are studying for an extended period of time. From Malinowski onwards, this method of embedded participation and observation "has enacted a delicate balance of subjectivity and objectivity", where "the ethnographer's personal experiences, especially those of participation and empathy, are recognised as central to the research process", whilst simultaneously being shaped by attempts at "impersonal standards of observation and 'objective' distance" (Russell-Bernard, 2002, p13). This practice continues to this day and is considered "at best, the author's personal voice, seen as a style" or tone, and at worst an "embellishment of the facts" (Russell-Bernard, 2002, p13). In order to acknowledge the limitations of this role and the very fact that it is a role, played by the researching field worker, contemporary ethnography is increasingly self-reflexive and aware that anthropology is part and parcel of that which it studies –culture (Spradley, 1980; Davies, 2008). Much of the reflexive discourse surrounding the role of the field worker focusses on the idea of the "participating observer" who simultaneously stands apart and within, engages and records, with the subject of investigation (Spradley, 1980).

In the 1980s a specific type of participating observational research emerged that drew upon much of the established paradigm of ethnography, but rejected any attempt at observer neutrality and located the researcher as a fully acknowledged participant who takes on an active role within the scenario being studied (Susman, 1983; O'Brien, 2010). This specific methodology has come to be known as Participatory Action Research (PAR) or more simply Action Research. PAR contains "such qualitative methodological approaches as phenomenology, ethnography, and hermeneutics" and "is characterised by a belief in a socially constructed, subjectively-based reality, one that is influenced by culture and history" (O'Brien, 2010, p6). It is a research method commonly used in practice-based research projects for the participating action researcher engages in continuous processes of "reflection-in-action" (Schön, 1991) and "recognises that there is little or no separation of research from practice, little or no separation of knowing and doing"

(MacIsaac, 1996, p4). Crucially, PAR is used in "real-world situations" and "is chosen when circumstances require flexibility, the involvement of the people in the research, or when change must take place quickly or holistically" (O'Brien, 2010, p5). In other words, a researcher using this methodology can also be a central player in the event, encounter or interaction under examination and can thus respond to and engage with actions as they unfold. By the same token, PAR proposes the notion that all people involved in the activity, whether or not they are the instigator of the project, can be regarded as researchers, due to the fact that they are participators. What each participant is finding out is as a result of their own personal participation, and thus research, that leads them to have an experience of learning (Ferrance, 2000). This point-of-view makes PAR a popular methodology for education researchers and practitioners (teachers) (MacIsaac, 1996; Mills, 2000; Ferrance, 2000).

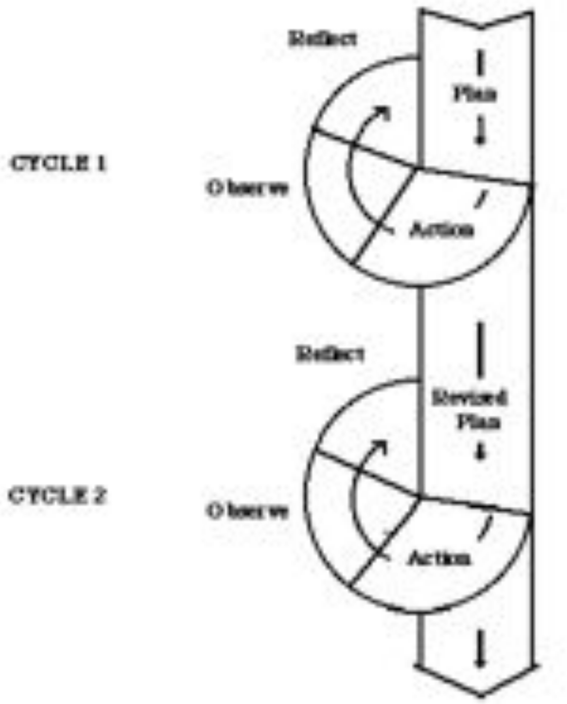

Figure 4.1: Action Research Protocol (Kemmis and McTaggart, 1988).

PAR foregrounds an ongoing process of engagement and reflection where "experiments are performed to bring about outcomes which are subjected to further analysis" (MacIsaac, 1996, p4). The notion of 'The Reflective Practitioner' was proposed by Donald Schön in *The Reflective Practitioner: How Professionals Think in Action* (1983) and states that the art of being an expert has at its core the idea of "reflection-in-action", where reflection takes place at the same time as the practice, and "reflection-on-action", where the practitioner reflects after the event

(Schön, 1991, p50). In essence, the practitioner engages in a process of thoughtful consideration of their own experiences and applies this knowledge to their ongoing practice and in doing so, acquires expertise (Regina Hatten and Salonga, 1997). This process, in relation to PAR, was proposed as the Action Research Protocol by Robin Kemmis (1988) and is graphically summarised in figure 4.1. As Dan MacIsaac explains, "this protocol is iterative or cyclical in nature and is intended to foster deeper understanding of a given situation" (MacIsaac, 1996, p2).

4.2 Applied Methodologies

> "The selection of method implies some view of the situation being studied, for any decision on *how* to study a phenomenon carries with it certain assumptions, or explicit answers to the question, *What is being studied?*" (Morgan, 1983, p19)

This section outlines how the relevant research methodologies of section 4.1 have influenced the methods of this thesis and introduces the specific research tools used. Figure 4.3 (located at the end of this chapter) provides a schematic overview of the following chapters that deal with practical explorations undertaken to examine the question of how the science of a material can be represent by the material itself within a materials library. Following the outline presented in figure 4.3, this section will take each of the Encounters/Events in turn, in order to demonstrate the similarities, differences and progression of methodologies present.

Chapters 5, 6, 7 and 8 present experiments with material-objects where material-objects are made and encountered by visitors to the Materials Library, whereas, chapter 9 describes experiments with encounters outside of the setting of the Materials Library. In all cases, visitors were a self selecting group, who presented a desire to visit the Materials Library by telephone or email. Events outside of the library were advertised on the Materials Library website, via the Materials Library mailing list (to which one could subscribe via the Materials Library website) and through the publicity channels of the host institutions.

In all cases of encounter/event, a cyclical methodological approach, akin to the Action Research Protocol (Kemmis and McTaggart, 1988) in figure 4.1, has been adopted. Figure 4.2 attempts to represent the progression from material-object to material-object, or from event to event in the manner of the Action Research Protocol diagram. This progression links together each of the chapters and their content through the repetition of structure but with variation of content. In each case, the structure applied has three dominant aspects: for the experiments with material-objects these are Making, Encounter and then Reflection; and for the experiments

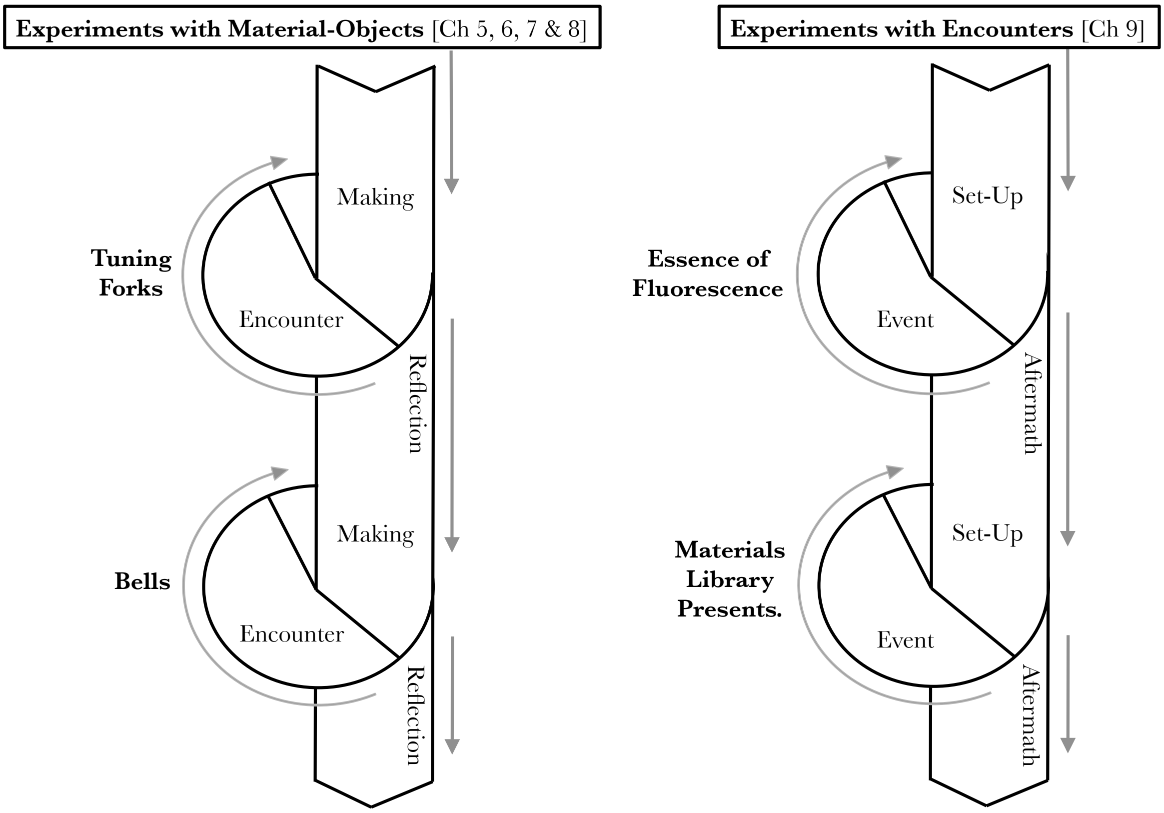

Figure 4.2: An illustration of the cyclical methodological processes that lead from one set of material-objects to another, as well as one staged encounter to another.

with encounters the three stages are Set-Up, Event and Aftermath.

As suggested by figure 4.2, there is a chronological order to the work of this thesis which should be acknowledged when considering the feedback cycle illustrated. The decision to make bells (chapter 7), for example, came out of the reflection period of the tuning forks (chapter 6), which in turn had come from the cubes (chapter 5). Equally, the work of the cubes, tuning forks and bells, forms an accumulation of knowledge for the author of this thesis (as an 'ethnographic field worker', 'reflective practitioner' and 'participatory observer') that influenced the creation of the spoons in chapter 8 and the selection of methodologies that were used to interrogate them. The same can also be said of the work in chapter 9 where aspects of the design of previous encounters influenced the design of the next as a result of reflection upon the successes, failures and opportunities present in each.

Central to each of the experimental chapters is the role of the author who is both deviser and instigator of this body of work. Influenced by the PAR model (Susman, 1983; O'Brien, 2010), and engaged in continual processes of "reflection-in-action" and "reflection-on-action" (Schön, 1991), the author is present throughout. Be it in the form of the materials librarian, host or facilitator of encounter, the author's role draws upon the previously outlined models of "participatory observer" (Spradley, 1980), "reflective practitioner" (Schön, 1991; Davies, 2008, p50), and "field worker" (Emerson et al., 1995). For the purposes of clarification, reference will be made to the author when active and declared responsibility for methodological decisions needs to be taken.

The following sections outline the specific methodologies employed in the experimental chapters of this thesis (chapters 5 to 9).

Cubes [Chapter 5]

The primary method used for gathering data on the cubes was that of ethnographic field notes (Emerson et al., 1995; Davies, 2008), taken by the author in order to log events and provide an archive of key words, phrases and descriptions of actions (Emerson et al., 1995). Every time a visitor came to the Materials Library, a sheet would be filled out that recorded the date of the visit, the general professional background of the visitor and notes on observed actions, interactions, and statements. An example of such field notes can be seen in Appendix G. Many visitors would take notes during their visit, writing down names or references that interested them. When the visitor adopted the position of note taker, the author would do the same and take occasional field notes in open view of the visitor. However, if the visitor was not keeping notes at any point, the author would make additional observatory notes immediately after the visit had concluded. It was felt that this parity of behaviour would make the visitor less likely to feel under observation or scrutiny, thus making the experience more naturalistic and representative of a typical visit. In addition, the participatory nature of the author's role was central to the running of the visit and thus a fully committed engagement with the visitor, and the material-objects, was paramount.

Visits were not video or audio recorded, for it was desired that visitors should feel uninhibited in their interaction with both the material-objects and the author (in the role of materials librarian). Equally, the architecture and arrangement of the Materials Library is such that no one camera position would capture all the activity that happened within the space. Visits were not framed as experiments within which there was a correct code of conduct, but rather the visit was observed as a 'real-world event' (an actual visit to the Materials Library by a member of the public). This was not difficult to do for each visitor was indeed a genuine visitor who identified their interest in the collection via email or telephone and made an appointment to view the collection and meet with the author to talk about materials. The use of 'real-world' visitors aligns the research with the methodologies of PAR, for as has been identified, “action research is used in real situations, rather than in contrived, experimental studies” (O’Brien, 2010, p5).

In many respects, visitors to the Library were interviewed in a manner which, in accordance with the ethnographic method, was ‘unstructured’ for it was predominantly conversational in style (Russell-Bernard, 2002). Interviews did not follow “a written list of questions and topics that need to be covered in a particular order” –one of the defining factors of semistructured interviews (Russell-Bernard, 2002, p205). On the other hand however, the experience of the visitor was not wholly without structure for it was arranged around a progression through the cubes. Starting with an encounter with the tungsten and aluminium cubes (see section 5.2.1), visitors were then introduced to the glass and acrylic cubes (see section 5.2.2), before moving on to the paraffin wax cubes (see section 5.2.3), the white chocolate cube (see section 5.2.4), and finally the aerogel cube (see section 5.2.5). In this regard, it is possible to argue that visitors to the library were interviewed in a ‘semistructured’ manner in accordance with the ethnographic methodology of using a pre-prepared “interview guide” (Russell-Bernard, 2002, p205), for the guide to the interviews was the cubes. In other words, the material-objects themselves become the methodological structure for encounter. That which “needs to be covered” (Russell-Bernard, 2002, p205) is embodied within each cube; it is the very material nature of the thing.

Over the course of this project, 460 visitors encountered the cubes within the materials library. Table 4.1 provides a breakdown of the professional backgrounds of each of these visitors. This information was recorded in order to gain statistical data on the professional profile of people interested in the Materials Library, as well as keep track of any relationships that might be observed between the backgrounds and interests of visitors and the types of reactions and interactions that occurred.

Data on the cubes was also gathered by weighing each cube on a set of digital scales. The results of this can be seen in table 5.1. This enabled specific, quantitative information about each cube to be known and any correlations between the comparative perceived masses and the actual mass of the cubes, to be judged.

Tuning Forks [Chapter 6]

The two primary methods used to analyse the tuning forks were participatory observation and acoustic testing. In the same manner as the cubes, field notes were kept by the author that documented the visitors’ interactions with the tuning forks and any comments made by visitors

Profession	Number of Visitors
Architect	27
Artist	53
Biologist	4
Chemist	6
Designer	46
Engineer	28
Jeweller	12
Maker	33
Materials Scientist	17
Media	24
Musician	21
Other	22
Physicist	12
Research Council or Funder	9
Student	117
Textiles	29
TOTAL	460

Table 4.1: A breakdown of the general professional backgrounds of visitors to the Materials Library from January 2007 to September 2009. Each of these 460 visitors formally encountered the cubes as a set of material-objects.

in reference to the qualitative experience of playing them. Due to the fact that the tuning forks were made after the cubes, in an attempt to explore a less abstract and more functional form, slightly fewer visitors to the Materials Library (418) encountered the tuning forks. Visitors who did encounter the tuning forks were free to play as few or as many of the forks as they wished, in any order they liked, and were asked to describe the differences between the sounds produced and discern the differences in pitch between forks.

In order to gather quantifiable data about the performance of each fork, audio recordings were made using MATLAB, an interactive environment for algorithm development, data visualisation, data analysis, and numeric computation (MATLAB, 2008). The standard MATLAB function, ‘wavrecord’ was specifically used to interface the acoustic signal and gather data on the quantifiable acoustic behaviours of each tuning fork.

Bells [Chapter 7]

The bells followed in the footsteps of the methodologies established in the tuning forks chapter, using both participatory observation and acoustic analysis as the primary sources of information on the material-objects and visitors’ interactions with them. The bells were devised and created in response to the cubes and tuning forks, as part of a reflexive and progressive methodology of material-object creation, where "experiments are preformed to bring about outcomes which are subjected to further analysis" (MacIsaac, 1996, p4), outlined previously in section 4.1.2 and illustrated in figure 4.2. In this case, the previous experiments performed were the creation and use of the cubes and tuning forks, the analysis of which was the encountering of them, which was reflected upon and responded to by the devising and making of a set of bells that were even less abstract in form, afforded a greater cultural object status, and provided a clear and resounding functionality. Due to the chronology of the project, fewer visitors again (328) were able to encounter the bells on visiting the library, for the bells were introduced to the collection after both the cubes and tuning forks.

Spoons [Chapter 8]

The spoons provided an opportunity to use material-objects as experimental equipment in order to discover new material knowledge through the application of a scientific methodology. Unlike the acoustic properties of materials (where the effects of material-change on the functionality of a tuning fork or bell are understood in relation to properties of density, elastic modulus and co-efficient of loss) the factors effecting the taste of different metals are less well known. Therefore, it was not possible to design the set of spoons to reveal and demonstrate something of the science of the materials, for the relevant science was not fully understood.

The study constituted a psycho-physical investigation into the perceived taste of the spoons and mapped these perceived properties against known scientific properties of the materials from which the spoons were made, in order to determine if there were correlations between the reported responses and materials properties. The design of the experiment is fully outlined in chapter 8 but recounted below in order to provide a full overview of the applied methodology.

Eight teaspoons (2x stainless steel, 1x zinc, 1x copper, 1x gold, 1x silver, 1x tin, 1x chrome) were laid out between two clean white kitchen towels. The temperature of each spoon was taken, along with the temperature of the room. Participants were seated in front of the covered spoons and talked through the experimental procedure. Once happy to continue, a video camera was set to record and the participant placed a blindfold around themselves to ensure the differing appearance of the spoons did not effect their responses.

The spoons were then uncovered and the handle of the first spoon placed in the hand of the participant, who then placed the bowl of the spoon into their mouth. After the spoon had been in the participant's mouth for three seconds, the experimental supervisor (the author) would then say an adjective and ask the participant to rate the spoons from 1 to 7 (a system based on the Likert scale) in accordance with the following subjective adjectives: cool, hard, salty, bitter, metallic, strong, sweet and unpleasant, in that order and fixed throughout the study. For example, if asked whether the taste of the spoon were sweet, the participant was asked to give a value between 1 and 7, with 1 being not at all sweet and 7 being very sweet. Participants were required to rate the spoons in the light of their previous experience of spoons in the world –a sense of an expected and experience state of 'spoon-ness'.

Through the course of the encounter, participants were free to take the spoons in and out of their mouths at will whilst considering and rating the adjectives. A glass of room temperature mineral water and a receptacle for the disposal of waste liquid was available for each participant, so that they could drink (and expectorate if desired) after the tasting of each spoon in order to cleanse and neutralise their palate. Participants were instructed to insure their mouth felt as neutral as possible before signalling their readiness to receive the next spoon.

Each participant tasted the spoons in differing, randomly generated orders, except for the first spoon which was always one of the stainless steel spoons. The randomisation of the order of spoon tasting insured that results would take into account any accumulative effect of such tasting. The two duplicate stainless steel spoons were included to test for the repeatability and consistency of the participants' blind subjective reports. Testing a spoon twice within the same test series enabled cross correlation of results to determine whether the participant reacted to the material the same both times.

Once they finished tasting the spoons, all spoons were washed in hot soapy water and then steam sterilised for ten minutes. Once sterilised, the spoons were removed, dried and left to cool to room temperature (repeatedly measured and found to be 21°C) before being wrapped in fresh kitchen towel ready for the next participant. Whenever the spoons were handled by the experiment supervisors, clean white cotton gloves were worn in order to maintain the sterilised status of the spoons. All sterilisation procedures were explained to participants before the experiment began in order to reassure them as to the safety of the task and care that was being taken.

Due to the use of human participants, the insertion of materials into an orifice and the use of video recording equipment, the study required full ethical approval. Application was made to the Ethics Committee of King's College London and approval granted as a result of the submission, a copy of which is documented in Appendix I. In total, 32 participants of mixed ages and both genders were recruited for the study, after being screened for any condition that would effect their ability to taste (see chapter 8.2 for further explanation of the recruitment process). Before the study commenced, all participants were required to sign a consent form (see Appendix I, figures I.11 and I.12).

The previous experimental chapters provided material-objects for encounter and used ethnographic methods to record the nature of people's interactions with them. In this chapter, data was gathered using both video recording equipment and Likert scale questioning in order to obtain objective measurements. The formation of a hypothesis, the application of controlled experiments within a laboratory environment and the acquisition of data that could be statistically analysed and plotted to reveal relationships between phenomena, sets the Spoons Chapter apart from the rest in its scientifically orientated rigour. It was framed as a PAR styled "real-world experience" (O'Brien, 2010, p5) within the context of a visit to the Materials Library. However, field notes were still taken in order to record the observations of the author who adopted the role of experiment supervisor. An example of these field notes can be seen in Appendix H of this thesis, where the formal Likert scale responses of participants were logged on the table and informally annotated by the authors's observations. The reason for this was that the author, despite acting as the objective supervisor, can still be regarded as a participating observer, accumulating knowledge and experience about people's actions, reactions and interactions with specific materials-objects. The making of such annotations acknowledges that whilst the methods of ethnography are unsuitable for gathering quantifiable and repeatable data, scientific methods of data gathering are often designed to do something very specific also have their limitations.

Speed Dating Materials [Chapter 9, Section 1]

The Speed Dating Materials workshops were run as participatory action research projects, hosted and facilitated by the author in the role of workshop leader and attend by participants from a variety of backgrounds, representative of the types of Materials Library visitors listed in table 4.1. All participants were made aware of the research-nature of the exercises before beginning and all contributions were deemed equally valid. As a research method, PAR proposes that all people involved in the activity, whether or not they are the instigator of the project, can be regarded as researchers, due to the very fact of their participation (MacIsaac, 1996, p4) (O'Brien, 2010, p5), thus foregrounding the learning experience of each participant (Ferrance, 2000). To this end, the Speed Dating Materials workshops were framed as learning experiences, where curiosity, discovery and multiple types of materials knowledge were to be celebrated.

The procedural methods of the workshop are documented in chapter 9.1. They involved the sequential revelation and stream of consciousness styled discussion of material-objects by participants within a given time frame. As well as taking field notes, the author recorded the audio of each workshop and later transcribed the text for analysis and documentation purposes. The use of this ethnographic method was particularly suited to the Speed Dating Materials workshops for the overt vocalisation of thoughts by participants was an integral part of the exercises. It is possible to then frame the resultant text as a self orchestrated semistructured interview where participants are both interviewer and interviewee, and the contents of each box provides the material-object provocation and semi-structured frame for discussion (see chapter 9.1.2 for examples of such transcriptions).

The Essence Of Fluorescnece [Chapter 9, Section 2]

The Essence of Fluorescence was a cabinet of fluorescent curiosities devised and created by the author and installed for three months in London's Hayward Gallery. A detailed description of the cabinets is to be found in chapter 9.2 but can be summarised as two identical cabinets, each with nine glass covered recesses containing different material-objects that each celebrated something of the wonder, surprise, beauty and curiosity of the phenomenon of fluorescence. Items included ranged from green fluorescent proteins to diamonds, human teeth to bank notes.

Analysis of *The Essence of Fluorescence* installation drew upon the methods of applied ethnography that focus attention on the behaviours of visitors in galleries and museums (Heath and Pettinari, 1998) and (Heath and Lehn, 2004). Taking the role of ethnographic field worker, the author located herself in the vicinity of the installation and took notes on visitor actions and interactions, whilst recording conversations for later transcription and analysis. Neither photographic or video recording equipment were used to document behaviours of visitors for the environment of the instillation was too dark and the gallery was not in favour of the use of either of these technologies for both ethical and copyright reasons. During the course of the exhibition a number of demonstration sessions were held in the space, within which the author was present. At this point she was also a participating action researcher and recorded observations and occurrences in the form of field notes.

In order to gather physical evidence of visitor behaviours within the exhibit, methods of forensic science were employed. In a forensic investigation and analysis, "the systematic documentation and recording of the crime scene is required" (Chisum and Turvey, 2000). This is commonly done through the gathering of trace elements for in every act of contact between a human and a human, or a human and 'thing', the human leaves behind a trace of themselves in a mutual act of cross contamination (Chisum and Turvey, 2000). A common way in which forensic science proves a human has touched a specific object is through the detection of fingerprints. In order to provide material evidence for the acts of touching that were occurring within the instillation, forensic fingerprint lifting techniques were employed. The glass windows of *The Essence of Fluorescence* cabinets were dusted with aluminium powder and then specially designed gel lifting plates were applied to transfer the powder from the window to the plate in a manner that enabled the resultant print to be examined and analysed.

Materials Library Presents... Tate Modern [Chapter 9, Section 3]

Materials Library Presents... Tate Modern was a series of four performative investigations, highlighting the art, science and materiality behind some of the works of art in Tate Modern's re-hung permanent collection. Each of the events took place within the gallery space of Tate Modern, focusing in turn on the four newly hung collection areas; Material Gestures, Poetry and Dream, States of Flux and Idea and Object. Chapter 9.3 focuses in detail on the content of the event as an experiment with the notion of encounter, but the central elements of each were specially created Materials Conjectures –tables at which a selection of material-objects were formally presented for visitor interaction. A capacity audience of 100 attended each night which was advertised via the Materials Library and Tate mailing lists, posters within Tate Modern and listings within the Tate magazine.

The specific collaborative behaviours of groups of people within galleries and museums is the focus of a number of research groups, within the fields of both science communication and museum studies, that utilise ethnographic methods in their anthropological research. Flagg (1994) in particular suggests people like to gather around and examine screen-based exhibits collaboratively, a finding supported by Meisner (2007) in her work with The Science Museum in London. Much research focuses on the conversations that ensue around such exhibits (Flagg, 1994; K.Crawley and Callanan, 1998; Ash, 2003), but Meisner et al. (2007) have begun to look at the actions of visitors, arguing that "shared experiences in the form of performative activity can both create and sustain visitor engagement" and that such experiences "arise both in and through" the performative actions of visitors (Meisner et al., 2007, p1532). In short, visitors are drawn into an engagement with an exhibit by the performative actions of others, and in performing such actions themselves, undertake a more sustained and in-depth engagement with the exhibit. With this in mind, the conjectures were presented as sites for the performative and collaborative activities of visitors through the physical coming together of people and material-objects, as well as a stage for the perforativity of the material-objects themselves. As the result of intensive ethnographic field work undertaken within The Science Museum, Meisner concludes that "shared experiences, and in particular performative ones, appear to be an effective means to create engagement and participation with museum exhibits and, subsequently perhaps, the scientific issues they contain" (Meisner et al., 2007, p1550). If this is true, the design and expressed celebration of *doing*, within collaborative materials encounters, may enable participants to engage more fully with scientific content and access scientific knowledge by means of the experiences, observations and conversations that are provoked and enabled by each Conjecture.

For this experiment with encounter there were five tiers of reporting that ranged from fully participatory to classically ethnographic. The first was the author who continued her role as the participating action researcher and compiled notes after each event based upon her observations and experiences. During the course of events she engaged with visitors and oversaw the entire operation in a stage managerial capacity. The second were the assisting Conjecturers who engaged with the visiting public and supervised Conjectures. These Conjectures were required to report to the author at the end of the event and feed back on the activities they observed. Questionnaires were provided for them to do this, as well as recounting directly in the first person. The third layer of reporting was undertaken by a team of ethnographic researchers from King's College London who specialised in audience/visitor analysis. This team observed the events, interviewed visitors, took photographs and kept notes during the course of the event before compiling a report on the events for the author. The fourth observing reportage was undertaken by a documentary film maker who provided a video record of the event that could be referenced and analysed by the ethnographers or author. The fifth and final tier of reporting participant was the visitor who was provided with the opportunity to verbally feedback to the curatorial team of the Tate and Materials Library at the end of the event and/or offer written feedback in the form of questionnaires that could be left with one of the curatorial team or emailed at a later date to the author. The primary reason for this scale of observation and the inclusion of a variety of methods was that the event was on a scale much greater than anything previously undertaken, and included many more people and activities than one person could reasonably observe. An opportunity therefore presented itself for the combination of observation methodologies and documentation techniques that had been used in previous experiments with both material-objects and events.

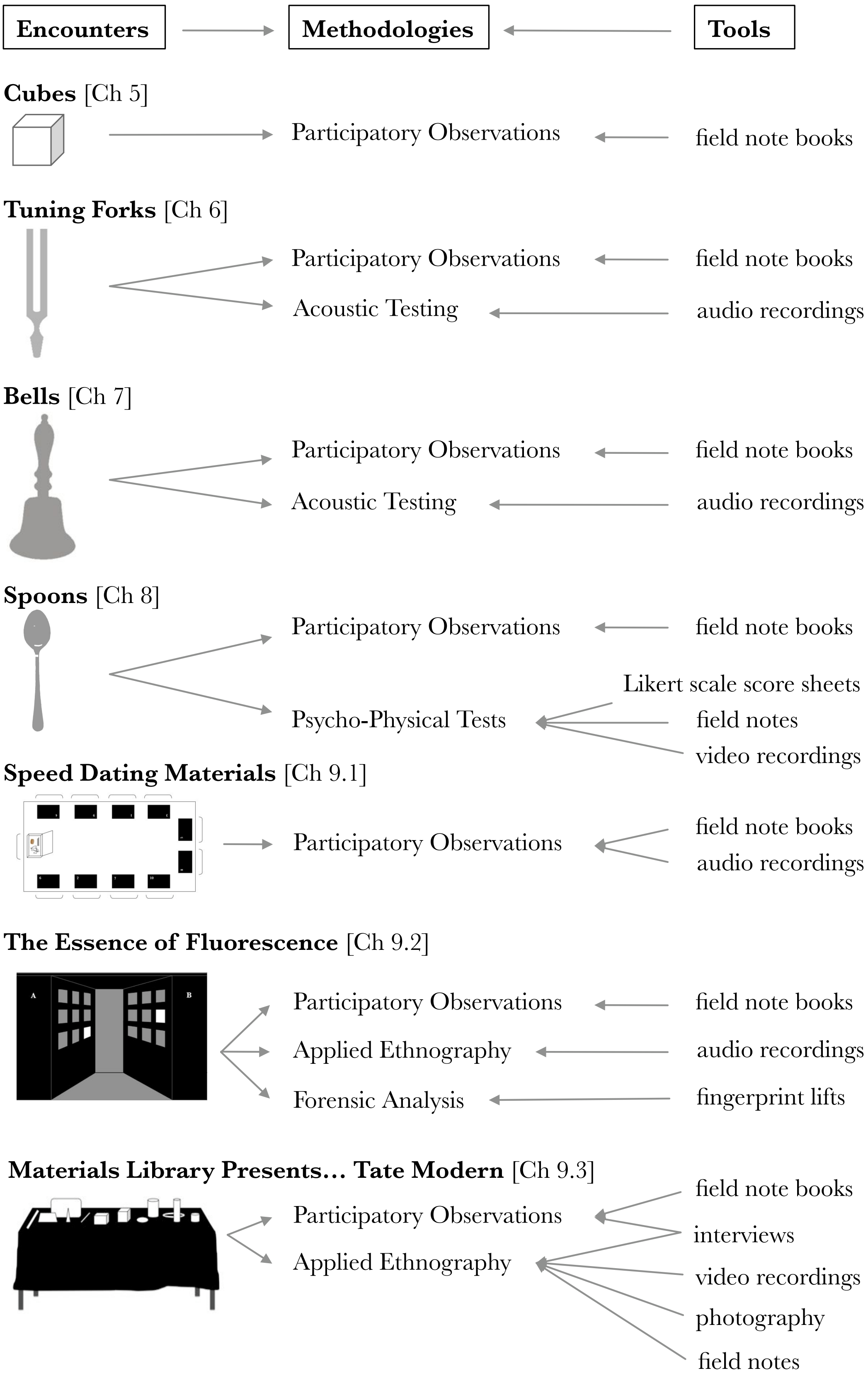

Figure 4.3: Overview of the Encounters/Events, Methodologies and Tools found in this thesis, organised in relation to the specific experimental chapters in which they were used.

Chapter 5

Cubes

This chapter is the first experimental chapter of the thesis that deals with the creation and use of sets of isomorphic material-objects within a materials library and the ability of these samples to represent the science of materials. The chapter begins by introducing the selected form of the cube and the methods and materials used to make each cube. It then presents five instances of encounter with specific cubes or pairings of cubes that highlight particular aspects of their materiality. Consideration is then given to the outcomes of these encounters in the form of reflections on specific topics applicable to the set as of cubes as a whole.

As has been shown in the sections 2.3 and 3.3, the form of a swatch is often that of a tile, disc or stick. The shapes are often flat so they can be easily stacked or strung together on chains, and not particularly large so as to produce a portable and economic method of presenting material samples (as was seen in figure 2.19). Such economies and decisions on form mean that what is often being presented is the surface of a material; a single plane that is to be interrogated with limited dimensionality and disregard for the solid, three-dimensional presence of the material (as outlined in section 3.3). The surface of a material is of course both interesting and important in the appraisal of a material's qualities and properties, but such samples do not provide the person handling them with an appreciation of the bulk of the material. In the case of solid matter, the physical presence manifested by its mass is what gives the experience of weight. In order to provide a form that would introduce bulk to a swatch and enable the material to be more three-dimensionally expressive, it was important to select a shape of object that could be recreated with ease in a number of different materials. To this end, the form of the cube was selected.

A hexahedron, or cube, is a three-dimensional solid form composed of 6 square faces, 12 edges and 8 vertices, with all angles equal and of 90°. The cube is one of only five Platonic solids; a type of mathematically regular polyhedron. The five Platonic solids are the tetrahedron, hexahedron (cube), octahedron, dodecahedron, and icosahedron. Their regular nature is defined by the common characteristics of their forms: all the faces of each solid are the same size and shape with all the angles identical throughout (Pappas, 1989, p110). As three-dimensional forms, all polyhedra (be they Platonic or not) are defined by the presence of flat surfaces and straight edges (Wells, 1995, p60). This means that any material formed into a polyhedron would enable the material from which it was made to be experienced under the mechanical conditions of the plane, the corner and the edge.

It was decided that the isomorphic set of cubes should be 4cm x 4cm x 4cm in dimensions, for this scale of material-object was small enough to be held in the hand, yet large enough to provide a feeling of material bulk. From this point on, in order to avoid confusion of dimensions, the isomorphic cube will be referred to as a 4cm cube, though it must be remembered that it is a cube with a volume of $64cm^3$.

The strong mathematical connotations of the cube as a form that exemplifies exactness, abstract geometry, non-representative reductionism were embraced by modernist architects like Le Corbusier or Mies van Der Rohe (Frampton, 1992) and minimalist artists like Donald Judd (Collings, 1999) or Sol LeWitt (LeWitt, 1990). The cube is an icon of perfection. Its straight lines, flat planes and right angled edges speak of mechanised processes of production. It is a form that promotes order, stacking or lining up. In fact, it is the ability of the cube to be mass produced and pack with ease in perfectly tessellating sets that makes it the favourite shape of stock and sugar manufacturers.

5.1 The Making

This section provides and overview of the processes and methods used to create a set of cubes of the same dimensions from a variety of different materials. Each cube was made as close to 4cm x 4cm x 4cm as the materials and making methods would allow. Table 5.1 lists each of the materials from which the cubes were made, the stock or source of the material, the method used to shape it and the final mass in grams of each cube.

Machining is a subtractional method of materials processing which involves the removal of material from an unformed work-piece to achieve the desired geometry by the use of mechanical cutting tools. The principal machines are lathes, saws, drills and milling machines. Lathes rely on the rotation of the work-piece to provide the cutting force and so are limited to producing

Material Name	Stock/Source	Forming Process	Mass g
Brass	block	machined	542.9
Copper	block	machined	571.7
Lead	pipe & sheet	cast then machined	668.2
Tungsten	block/Wolfmet	machined	1179.9
Aluminium	pipe	cast then machined	173.8
Bronze	ingots/Meltdowns	lost wax cast	548.3
Phosphor Bronze	block	machined	568.9
Nickel Aluminium Bronze	block	machined	484.90
Sintered Bronze	powder	cast	373.3
Mild steel	block	machined	500.2
Cast Iron	old lathe bed	machined	450.7
Solder	wire	cast	576.3
Monotype metal	type	cast	433.0
Titanium	block/McLaren	machined	262.8
Zinc	sheet	cast then machined	373.2
Concrete	powder	cast	119.7
Glass	Tokyu Hands	cast	152.4
Acrylic	transparent	cast	79.1
Paraffin Wax	pellets	cast	53.8
Liquid Paraffin Wax	pellets	cast	49.3
Wool	sheet insulation	trimmed	2.8
Vulcanised Rubber	Tokyu Hands	cast	87.1
Black Nylon	block	machined	73.1
Food Grade Nylon	block	machined	73.1
Blu-Tac	packet/Bostik	moulded	128.4
Plasticine	packet/Newplast	moulded	119
Tufnel	block	machined	79.2
Starch	powder	rapid prototyped	62.2
Modelling Foam	sheet	cut	3.3
Polystyrene Foam	sheet	cut	1.9
Aerogel	Silica/NASA	supercritically dried	0.?
Balsa	beam	machined	7.9
Iron Wood	block	cut	80.5
Mahogany	black	machined	33.6
Oak	2x4” beam	machined	41.0
French Walnut	block	machined	37.0
Ebony	block	machined	68.0
Ash	block	machined	45.5
Maple Plywood	sheet	glued & machined	39.5
Pine	block	machined	29.4
Piranha Pine	block	machined	35.2
Pickled Pine	railway sleeper	machined	49.4
Clay	dug	moulded	106.5
Jelly	block/Rowntree’s	cast	72.0
Sugar	granulated/Tate & Lyle	moulded	82.6
White Chocolate	bar/Green & Black’s	cast	66.3
Dark Chocolate	bar, 74%coco/Menier	cast	114.1

Table 5.1: A list of materials that have been made into 4cm cubes with a reference to the process by which each cube was made along with their measured mass (g).

rotationally symmetric geometries. Saws, drills and milling machines operate on a stationary work-piece, with the cutting force provided by the linear or rotating motion of the cutting tool. Machining processes often involve considerable heat generation which can alter the microstructure of the material being machined as well as the cutting instrument and so they may be accompanied by a system of liquid or gas cooling. This process is often fully mechanised in an industrial manufacturing setting via a process called Computer Numerical Control (CNC). However, hands-on involvement of a machinist to manipulate, position and apply tools is common in small scale industrial operations, in the Craft industry, and in the production of Art. This method of machining was used to create the majority of metal and wooden cubes in the collection.

The second main processing method was casting. This is a process where materials are melted and then poured into a mould, subsequently solidifying into a geometry determined principally (but not completely) by the internal dimensions of the mould. In order to create cubes of the desired 4cm dimensions, a bespoke mould was made from aluminium by machining six individual plates from the six sides of a cube so that when assembled with screws it described an internal volume of 64cm^3. The design of the mould was such as to enable the sides to be removed sequentially, enabling the cast solid cube to be removed undamaged, see figure 5.1. In some cases mould release agents were also employed to the inside of the mould to minimise the adhesion of the cast cube to the mould. The melting points of the cast materials was one of the factors that limited the selection of materials for casting. The melting point of aluminium is 655°C, thus it was crucial to not pour into the aluminium mould a liquid of a greater temperature that would melt or soften the mould.

A few cubes (such as the plasticine, starch and aerogel cubes) were made using processing techniques other than machining and casting. The processes are those such as moulding through pressure (a manual method) (Hamer and Hamer, 2004), 3D printing (a digital fabrication method) (Ashby and Johnson, 2002), and perhaps the most exotic, super critical drying using an autoclave (JPL, 2002).

The specific manufacturing process of each cube depends greatly on the properties of the material, and indeed whether the material can be formed into a cube at all. For instance, although the use of a higher melting point mould material would have allowed the production of a steel cube via a casting method, it would not have allowed the production of ceramic cubes since the melting of ceramics is not possible even with commercial furnaces. The point is equally true of the wooden cubes but for different, though obvious, reasons. Thus different materials lend themselves to different processes due to their different structures and resultant

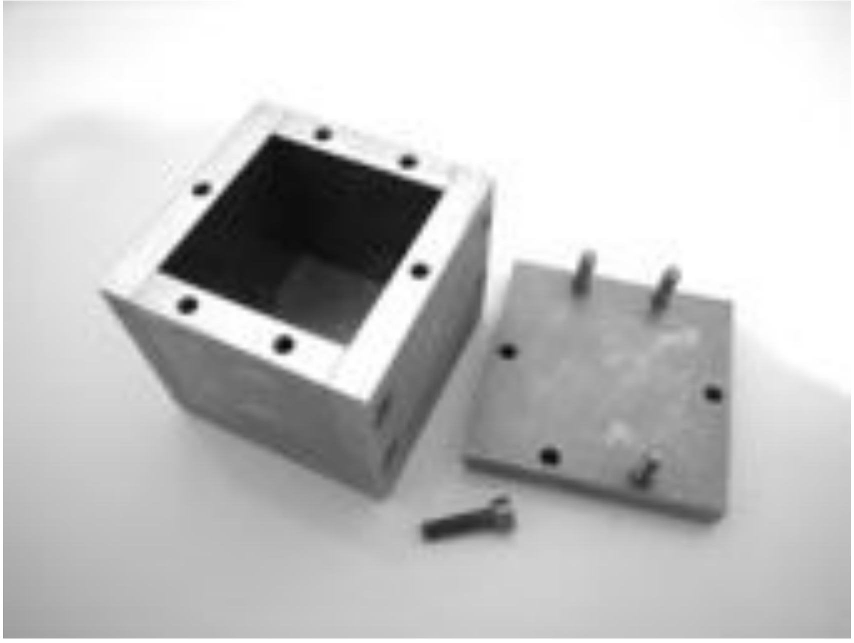

Figure 5.1: A mould made from aluminium with an internal volume of 64cm^3. Each side is held in place by a hex/allen key head screws.

thermo-mechanical properties (Martin, 2002).

It should be noted that the issue of which might be the ‘best’ process to produce a cube of a given material is not solely determined by the materials science. This is because it is a central tenet of materials science that the process determines the materials structure and so ultimately, even though the same cube in terms of its composition could be made by two different methods, they would not have the same materials structure and so technically are not exactly the same material. The difference in properties of wrought steel versus cast steel illustrates this point very well –processing affects properties. Thus ultimately in the context of developing a methodology for exploring materials science through the materials themselves, the notion of the ‘best’ process is not a meaningful term. Other factors such as desires, opportunities, access, availability and practicalities played an important part in the selection of the manufacturing processes for the cubes. Difficulties in sourcing sheets of sufficient thickness or blocks with volumes large enough to machine a 4cm cube, demonstrates one obvious limiting factor, that of stock availability. Thus choices were inevitably made between competing processes to produce a cube that represented a particular class of material, and these were dominated by two principal concerns: cost and time constraints.

5.2 Encounters

This section offers descriptions of encounters of visitors with specific cubes that took place within the Materials Library as experiments in the capacity of materials to display their own properties, with observations and reflections on each. Visitors were interviewed using a semi-structured method, as introduced in chapter 6.2, that saw the cubes presented as the "interview guide" (Russell-Bernard, 2002, p205). The entire collection of cubes was displayed to visitors on a shelf within the library but they were encouraged to begin exploration by sequentially handling the specific cubes outlines in this chapter, in the order in which they are reported in this Encounters section (first the tungsten and aluminium cubes (section 5.2.1), then the glass and acrylic cubes (section 5.2.2), next the paraffin wax cubes (section 5.2.3), then white chocolate cube (section 5.2.4), and finally the aerogel cube (see chapter 5.2.5)).

Visitors were observed using the participatory action research method (MacIsaac, 1996) (O'Brien, 2010) (see section 4.1.2), with the author taking field notes during and after each visit in order to gain an overview of broad trends and patterns of visitor behaviour. The absence of a fully structured interviews or feedback forms insured that the visitors did not feel that they were being examined but simply engaging in a visit to the library with the author as the host. During the course of this work, over 460 visitors of varying professional backgrounds attend the library. An overview of the professions of visitors can be seen in table 4.1 and Appendix F. Reference to the author's field notes will be made throughout this thesis and where directly cited, the date of the visit will be given. Due to the fact that a visit to the Materials Library, and thus the encountering of material-objects was a dynamic scenario, the participatory observations of visitor behaviours and interactions made by the author and recorded in field notes were of particular importance for there is always information "that cannot be accessed by simply asking informants to discuss meanings and interpretations" of specific actions, events or objects (Davies, 2008, p51). A representative sample of the field notes can be seeing in Appendix G. Each encounter in this section focusses on one or two specific cubes from the collection and documents relevant information about the materials and describes acts of encounter that pertain to the cube in question.

5.2.1 Tungsten and Aluminium

At its core, this encounter is about forming a comprehension of relative densities through experiential comparison. Thus this encounter first and foremost, is designed to offer a clear insight into the world of metals through a comparison that elicits surprise. This encounter deals with the experience of lifting of the tungsten and aluminium cubes; two cubes of equal volumes but differing masses.

About the Materials

Figure 5.2: The 4cm cubes of tungsten (left) and aluminium (right).

Tungsten is an extremely tough metal, difficult to machine, with the highest melting point of any metallic element at 3422°C. It has a density of 19.3 g/cm^3, making it the heaviest of all the cubes with a mass of 1179.9 g. Aluminium, in contrast, is an extremely light metal with a density of 2.70 g/cm^3, and as a 4cm cube its weight is 173.8 g (thus it is ten times lighter than tungsten). It is ductile and malleable, making it suitable for machining and extrusion, and thus a relatively easy metal to form and work. Both cubes were shaped into the desired dimention through the use of a milling machine, but were not polished or in any other way post-processed. The cubes are similar in appearance for both have metallic grey surfaces –though the tungsten is darker with a smooth sheen to it, whilst the aluminium cube is lighter in colour with a more diffuse sheen, as shown in figure 5.2.

Some people may be aware that tungsten has a very large atomic weight and thus forms a high density solid, though many are simply familiar with the name of the material rather than its properties. It is extremely unusual to have even seen a piece of tungsten other than the tiny filament of a light bulb, and then in a form so small as to render virtually impossible any appreciation of its density. Most people's direct experience of aluminium is in the form of tin foil, drinks cans or cooking pans. Even with larger items such as these, the appreciation of aluminium's extremely low density is obscured by the effectiveness of its use or application as a material.

Instance of Encounter

The two cubes were typically presented side by side, not touching each other. No labels giving information about the cubes were included, neither were there labels prohibiting the touching of the cubes or instructing a specific interaction. Two main modes of encounter can be identified, the first involving a singular investigating visitor, and second involving two or more visitors who may or may not have known each other prior to the encounter.

In the primary mode, a singular visitor is confronted with two metal cubes and typically lifts it vertically to about a height of around 20cm, then placing it back down before lifting the other cube in the same manner. The moment of the second lift is significant, the extreme sensation of the different weights being impossible to ignore, whatever the physical strength of the visitor –a strong woman is as amazed as a small boy. Once experienced, the visitor typically returns to alternately lifting the two cubes, checking the sensations and enhancing the comparative experiences and the body of knowledge this affords the visitor.

Visitors were free to lift either cube first. The vital aspect of the experience was that one cube is lifted in the hand, followed by the second cube being lifted by the same hand. Upon lifting the second cube, the first impulses of lifting are either futile as the cube does not rise as expected, or are exaggerated as the cube rises very quickly, depending upon whether the lighter aluminium or heavier tungsten cube was encountered first.

If a visitor lifts the two cubes simultaneously, one in each hand, mimicking the posture of an analogue scale balance, the encounter was less likely to illicit an initial instance of verbalised surprise form visitors. Although this posture enables the visitor to gently bounce the masses up and down, giving one cube their attention and then the other in an attempt to ascertain which is heavier, the effect is not as great as the single hand encounters.

When more than one visitor engages with the cubes, many different behaviours are observed. 1) In a group experience, one often observed behaviour consists of the following: one visitor, having experienced the two cubes on an individual basis, then stages the encounter for a second visitor. The experience of the second visitor then varies according to a number factors controlled by the former. For example; a) The initial visitor may directly tell the other about their experience before they get a chance to experience it for themselves. b) The initial visitor may also place or drop the cubes into the hands of the other, allowing both cubes to be experienced simultaneously. 2) Alternatively, the initial visitor may indirectly reveal something of the experience to the other though a) anticipatory facial expressions or b) by placing the cubes down in front of the other, thus generating differing acoustic signatures for each cube that clearly mark one out, through depth and volume of tone, as heavy and the other as light. 3) In a much larger group of visitors where there is no definable initial visitor, many more variables are introduced. As soon as one cube is placed down, someone else picks it up, possibly passing it onto someone else without realising there is a companion cube. The time between holding each of the two cubes increases, preventing direct comparison. Indeed, something else may even have been held in the visitors hand in the meantime. 4) When initial visitors staged an encounter for others, they did so from a knowledgeable position, achieved through the encounter they had just experienced. We can assume that they would not go to the trouble of setting up the experience for others if they had not found it interesting and revelatory.

No matter how many visitors were engaged within an encounter, the tungsten cube was never correctly identified. If an attempt was made at identification, the more common assumption was that the cube was made of lead. In contrast, the aluminium cube was nearly always identified.

Responses and Observations

The greatest effect is elicited when the lifting of the cubes occurs one after the other with the same hand. This mode of encounter enables the comparison of the two cubes with the most dramatic effects, with people exclaiming with surprise and wonder that two metals could have such staggeringly differing weights. Exclamations of surprise along the lines of “gosh, yes, amazing difference” (31-08-07), “I was not expecting that!” (13-07-08), “where’s the magnet” (12-01-08) and “that is heavy, I’m shocked” (03-11-08) were often heard. However, it was reported and observed that the experience was more surprising (indeed better) when the aluminium cube was lifted first and followed by the tungsten cube, as the heaviness of the tungsten cube acted as the punch-line of the encounter and thus sits better at the end of the encounter. These effects are probably attributable to physiological functions, as will be discussed in the conclusion.

A loss of surprise in experiencing the contrasting weights and a dilution of the power of the encounter was also found when there was more that one visitor involved in the encounter. In general, the actions of the initial visitor diminish the impact of the experience that can be had with a single-person encounter. It is notable that initial visitors did not decide to simply describe to the others the nature of what they had just felt, but to prompt the others to physically experience it for themselves. The actions of the initial visitor can however, result in the loss of surprise on the part of the second visitor, when they eventually experience for themselves the sensation of lifting the two cubes. Greater numbers of people introduces greater numbers of variables to the encounter, thus diluting the intensity of the encounter as the physiological purity of the originally designed experience is diminished.

Visitors draw on a variety of prior cultural references and experiences in the attempted act of materials identification. The vast majority of visitors are underexposed to tungsten therefore they do not recognise it in this form. An appreciation of the weight of the cube as an indicator often leads visitors to incorrectly identify the material as lead, as they seek to align the experience of the heavy cube with their cultural knowledge of metals. Statements like "is this lead?" (03–04-07), "this has to be lead" (06-10-08) or "the only metal I know that could be this heavy is lead" (03-28-09), demonstrative the desire of visitors to engage in acts of materials identification that requires prior knowledge or experience of material properties. In the case of aluminium, visitors do have both cultural and physiological memories of the material. Appreciation of the metal as being light-weight is coupled with experiences with aluminium foil, drinks cans and kitchen pots and pans. This often lead to correct identification of the material.

Cultural and physiological factors contribute to the experience that the visitor gains from the encounter. Some of these were built into the design of the encounter and some were discovered through the enactment of the encounter. As the entire encounter is structured around interlocking variables and constants in the materials and shapes of the cubes, the introduction of the multiple variables engendered by the visitors themselves brings further cultural and physiological factors to light.

This encounter is designed as a comparison for heightening the visitors' sensitivity to the properties of these metals. The repeated act of lifting establishes a memory in the musculature of the participant, generating an initial action and gesture of lifting that is perceived as adequate and rational for an object the size of the cubes. A memory of this experience and the physical perception of it, then acts as a template against which the lifting of the second cube can be measured. However, factors of time, technique, and individual physiology, all lead to variations in the encounter experience.

For example, in the case of physiology, people are either right or left handed and more used to doing things with their dominant hand/arm, resulting in the development of different strengths and sensitivities in each hand/arm. In single visitor/single arm encounters, the use of the same arm, and the same action with the different cubes, negated the effect of variations in the strengths and sensitivities between arms: it did not matter which of their arms the visitor used, simply that it was the same one used each time to lift each cube. The variables of arm and action are kept constant, enabling the visitor to focus upon that which differs –the cubes' weights.

Visitors bring to the encounter previous experiences of weight in relation to multiple and varied forms of materials, encountered in everyday life. This designed encounter heightens their awareness of their accumulated phenomenological knowledge and enables them to bring the phenomenology of weight to bear on their understanding of mass. However, the encounter did not prompt a formal scientific understanding of mass in relation to density, atomic mass or the atomic nature of matter in general.

In some cases, the problem of varying techniques of lifting, notable gaps of time between lifting and the uncoupling of the cubes as an comparative unit to be encountered together, meant that in many cases, the contrast between the mass of the aluminium cube and that of the tungsten cube failed to be appreciated. These points serve to highlight the importance of lifting and provide evidence to support the hypothesis that the physical encountering of matter, in the form of a material-object, acts as a revelatory agent of materiality and the perception and comprehension of properties.

Prior cultural knowledge is significant in the encountering of the tungsten and aluminium cubes as noted in previously in Responses and Observations. Whether or not the visitors identify the materials correctly is not at issue here: simply through and in the act of attempting identification, visitors reveal cultural knowledge of materials and physiological understandings of their properties.

Varying visitor numbers introduces a final variable into the encounter. An increase in simultaneous visitor numbers decreases the access individual visitors have to the cubes, thus the impact of the experience, as designed, is diminished. The pairing of the two cubes together, as a singular phenomenological experience, is lost due to the fact that so many people are now keen to handle the cubes, leading to too much time elapsing between the lifting of the two cubes.

However, multiple visitor encounters did open another mode of behaviour in that they provided a forum for the shared discussion of the experience between visitors and the joint affirmation of their reactions to it. This provides a context for the confirmation of the visitors capacity for judgement based on their sensory experiences of the materials.

5.2.2 Glass and Acrylic

This encounter focusses on a comparison between two visually similar cubes and considers the way in which physical encounter enables material identification. The encounter is designed to show how touch can be used as a tool for material discrimination that can challenge assumptions based on visual cues. As a result, the specific effect of thermal conductivity is identified as central to the differentiation between the similarly transparent cubes of glass and acrylic.

About the Materials

Glass is a hard, brittle, amorphous material that, when heterogeneous at a length scale greater than the wavelength of visible light, is transparent solid. Common applications of glass are evident on a daily basis in windows, lenses, light bulbs and bottles, to name but a few. Pure silica glass (SiO_4) has a density of 2.203 g/cm^3, a high melting point and is extremely viscous even when molten, making it difficult to manipulate. In order to produce glass on an economically viable scale, metal oxides are combined with silica to produce glasses with lower melting points, thus making them easier to work and use in manufacturing processes (Martin, 2002). Different applications of the material utilise different properties and many developments and techniques in the material science and engineering of glass give rise to less obvious manifestations of the material: toughened glass, suitable for use where other glasses would shatter; fibreglass, where short lengths of glass fibre are mixed with different types of polymers in order to reinforce them and produce tough light weight structures; or fibre-optic cables, where long lengths of flexible glass fibres are used to transmit light and carry data. In most uses of glass it is the optical properties that are most highly prized.

Polymethylmethacrylate (PMMA), more commonly known as acrylic, Perspex™or Plexiglas ™, is a tough rigid polymer that is noted for its thermoplastic properties and transparency. It has a density of 1.19 g/cm^3, less than half the density of silica glass, but is more easily scratched than glass due to its reduced hardness. Acrylic can be easily cut by blade or laser, worked with a variety of tools, or cast as its melting point is between 130-140°C. Common applications of the material range from display units to riot shields, utilising the material's two main properties of toughness and transparency. Acrylic is also used to create polymer optical fibres that offer a cheaper alternative to glass, though a less efficient transporter of light, especially over long distances.

Instances of Encounter

In this encounter, two apparently identical transparent cubes were presented side by side to the visitor; one made from solid glass and the other from solid acrylic. No label declaring any information about the cubes was given, nor any verbal cue to these being different materials. Visitors were invited to attempt an identification of the materials and were free to pick each cube up in their hand, examining it both visually and haptically, as part of their materials identification process. To this end, two main modes of encounter were identified; the instance with a singular investigating visitor, verses the instance with two or more visitors attempting to identify the materials.

Within the first instance of encounter it was possible to identify two sequential steps employed for materials identification. Initially the visitor simply regarded the cubes visually, appraising the identical nature of their forms and the transparency of the materials. From here the visitor progressed to handling and feeling the cubes, either one at a time followed by simultaneously handling, or immediately handling the cubes at the same time. Once the cubes were picked up, visitors occasionally bounce them up and down in the hand to judge the relative weights of the cubes, many ran their fingers across the surface and edges of the cube, and in some cases, knocked the cubes together or onto their teeth, in order to generate a sound from the material. The majority of visitors held the cubes up to their face and rotated their wrist, enabling a closer visual examination of the cubes from a number of angles. They also held one or both of the cubes up to the nearest source of light or simply peered at the room through the cube itself to examine its optical properties.

The second instance of encounter includes much, if not all, of the investigating steps of the first instance but is differentiated by the presence of two or more visitors, both engaged with the task of materials identification. In this case, the cubes were passed between visitors and discussed whilst both the haptic and visual appraisal of the cubes commenced. The actions and reflections of one visitor often influenced those of the other in a shared exchange of opinion and methods of interrogation.

Responses and Observations

When simply examining the cubes visually, many visitors found it difficult to differentiate between the two cubes and were more inclined to assume they were the same material (glass), based on the degree of characteristic transparency observed. As a result of handling, every visitor was then able to identify the glass cube, and the acrylic cube as, at the very least, a type of ‘plastic’. In these cases of successful material identification, a number of reasons were cited and key experiences within the encounter highlighted as contributing factors that enabled the correct identification of the materials.

Upon touching the cubes, many visitors were able to correctly identify the cube of glass, due to the relative coolness of the material. This method of materials identification was revealed by statements like “this has to be the glass one, it’s much cooler” (03-28-09). The difference in the surface temperatures of acrylic and glass, as experienced by touching them, is due to differences in the thermal conductivity of the materials. Glass is an efficient thermal conductor (1.05 W/m K), meaning it transfers heat from the hotter to the cooler faster than acrylic (0.2 W/m K) and is therefore perceived as cooler to the touch.

Another factor cited as a reason for the correct identification of the materials was that the glass cube 'felt harder', with specific observations being made about "the feel of the edges" (03-04-07). Hardness is defined in materials science as the resistance to indentation and is related to associated properties such as strength, yielding and work-hardening (Martin, 2002). Many methods for testing hardness involve the application of a microscopic probe with specific force and the examination of the impact this had upon the material. One such method is the Vickers Hardness test –the standard method for determining hardness in metals and a common way of measuring hardness in many materials (Ashby and Johnson, 2002). This test involves the applications of a pyramid shaped diamond probe at a known pressure, for a known length of time, to the surface of a material. Once the probe is removed from the material, the angle of the diagonal indentation is measured, enabling the calculation of the Vickers Hardness (HV). Whilst handling the cubes of glass and acrylic, no formal mechanical tests for hardness were conducted, and many visitors did not even attempt to dig a finger nail into the surface of the materials or scratch one cube against the other to determine which was the harder. However, the notion of hardness as perceived by the visitor was simply cited as a something 'felt'; an empirical observation made through the sense of touch. When asked *why* the glass cube felt harder, some visitors replied that they did not know or could not exactly say, whilst others referenced specific aspect of the feel like the "sharpness of the edges" (10-05-08), the corners (30-08-07), or that "the glass cube was colder" (17-07-07), (30-09-08) (03-28-09) and (25-02-09). Although thermal conductivity is not usually used as a test for hardness, when thermal conductivity is plotted against hardness (HV), as seen in figure 5.3, there does appear to be a degree of correlation between the hardness of a material and its thermal conductivity. Figure 5.3 clearly shows that for the case of acrylic PMMA, that can be seen stretching along the top of the cluster of blue ellipses, and the glasses within the pink ellipses which is both harder and more thermally conductive than acrylic.

This result suggests that the cultural coupling together of 'cold' with 'hard' is based upon a 'synaesthetic' appreciation of materials and their properties, where one input of one sensual dynamic (coldness) can suggest and offer the experience of another material dynamic (hardness). By the same token, the pairing of coldness with hardness is placed in binary opposition with the sensations of softness and warmth -an indication of the ability of our senses to evaluate and identify materials through touch and map materials and their relationships to one another in the experienced environment through sense data.

As outlined, material temperature and hardness were often cited as the key to materials

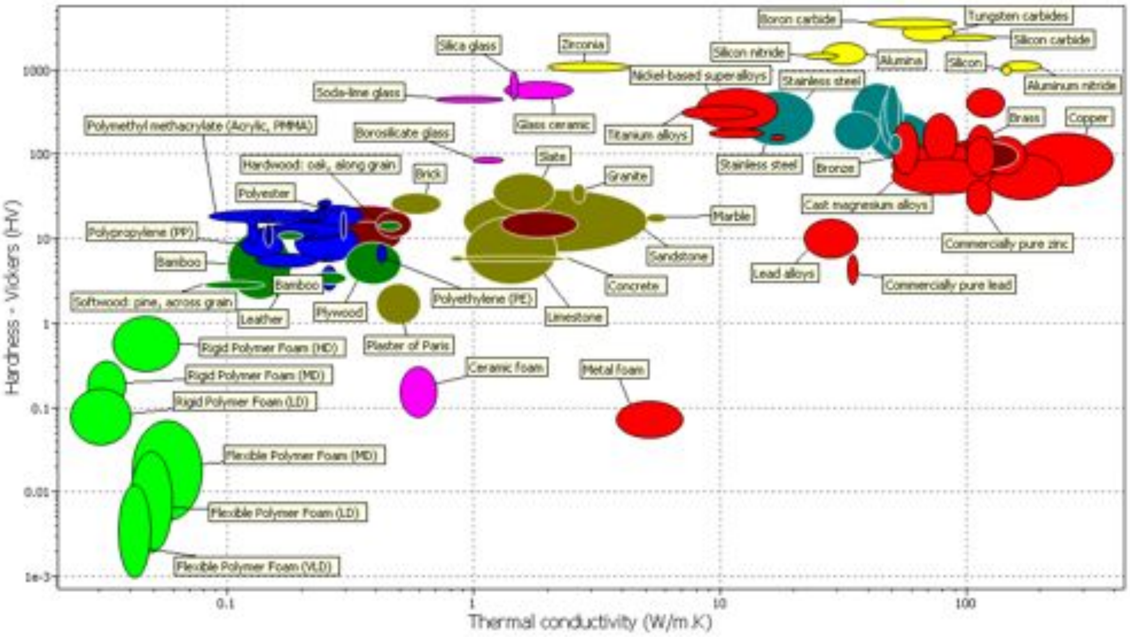

Figure 5.3: The properties of hardness (Vickers Hardness) and thermal conductivity plotted against each other on a multi-dimensional scaling map generated using Cambridge Engineering Selector (as introduced in section 2.2.1).

identification and differentiation between the cubes of glass and acrylic. However, a number of more subtle factors were also reported; namely, mass, sound and appearance. The glass cube, upon lifting, was evidently of a greater mass, but the difference in the masses of the glass and acrylic cube did not generate surprise and was not especially remarked upon.

When some visitors bought the cubes to their teeth in an attempt to generate an auditory signature from the material by tapping it, a difference in the sonic sensation produced was observed. The glass cube gave a characteristically higher, brighter tone, whilst the acrylic was duller in tone and pitch. These sounds acted as auditory cues for material recognition, adding to the procedure of identification for those who experienced it. It must be noted however that the correct identification of a material by this method, is not wholly based upon the sounds produced. Bringing a material up to the teeth inevitably means bringing it into close proximity with the mouth and possible even in contact with the lips, an area of the body highly tuned as sensual tool. If the lips touched the cube, even for an instant, the perception of the materials thermal properties would be achieved most readily, thus enhancing and supporting thermal observations previously made.

Once the differentiation between materials has been achieved by the visitor through touch, previously unobserved or unarticulated visual differences between the cubes become apparent.

Initially the immediacy of the tactile experienced dominated over the subtleties of the optical differences, but once established, the tactile experience feeds back into the visual appreciation. Very slight bevelled edges could be felt and were then noticed on the edges of the glass cube. These bevels had been put in place by the manufacturer to reduce the risk of cutting due to the sharpness of raw glass edges, in turn demonstrating that nuances of form and manufacturing techniques are a direct result of the material used. As well as this slight difference in form, the quality of light the passing through each of the two cubes was also identified as different between the glass and the acrylic cube, resulting from variations the the refractive index of each material.

All of the above discoveries of material properties pertaining to temperature, hardness, mass, sound, optics and form were experienced in both individual and many person encounters. Within the latter category of encounters however, the fact that more than one person is engaged with the task of materials identification had a direct impact upon that which was encountered. The repeated handling and passing round of the cubes by a number of people meant that the cubes warm up through repeated and prolonged contact with the human body. The result of this is that the temperatures of both cubes increased over the course of the encounter and for those people who held the cube nearer the end, the experience of the relative coolness of the glass cube was substantially diminished.

Conversely many-person encounters gains over the individual encounter by the opportunity it affords for discussion amongst visitors. Experiences can be shared, assumptions challenged and agreements come to over the nature of the materials. One visitor may take the lead in the encounter, going first in handing the cubes and possibly declaring their opinion on what they are made from. In this case any subsequent visitors who hear the pronouncements of the first visitor, will have a different form of encounter, testing the affirmations that came before and seeing if they concur. One visitor may indeed possess specific and applicable knowledge which they share with the other visitors and begin to have broader and more wide-ranging material conversations.

Be it through the experience of the individual, or the collective response of a group of visitors, an encounter with the glass and acrylic cubes challenges the visual sense as a reliable mode of materials identification and foregrounds the power of touch to reveal materiality and understand properties of matter.

5.2.3 Paraffin Wax

At its heart, this encounter is about forming a comprehension of material transformation and state change through experiential comparison. The encounter is designed to offer an insight into the effect of processes on materials and their forms. In this encounter, materials identification is of less relevance than process identification, with two cubes of paraffin wax presented as illustration.

About the Material

On the molecular scale, paraffin wax is a saturated hydrocarbon molecule containing 25 carbon atoms and 52 hydrogen atoms ($C_{25}H_{52}$) and as a result, is extremely hydrophobic, making it suitable for use as a protective ‘waterproof’ coating on fabrics. Other common uses for the material include candles, polishes, and as a preservative and aesthetic coating on some fruits. In solid form, it is white with a light oily sheen to its surface. It is a comparatively brittle wax, so care must be taken when working or carving fine details as the material is liable to chip. It has a density of 0.93 g/cm^3, and a mass of 59.92 g when in the form of a 4cm cube. With a melting point of between 50°C and 60°C, it can be easily cast and appears transparent when in its liquid phase. On solidification there is a notable degree of shrinkage in the material, resulting from the decreased volume in solid phase.

The creation of the two different cubes of paraffin wax used for this encounter was achieved through casting. In order to understand the difference between the two cubes, made from the same material, it is important to know the following processes used to create them. For the first cube, white beads of paraffin wax were placed inside a Pyrex beaker to a depth of 5cm and then heated with a gas blowtorch until fully liquified and transparent. This liquid was then poured into the bespoke aluminium mould until the liquid was level with the rim of the mould. The wax was then left to cool and solidify, after which, the sides of the mould were unbolted and the wax cube removed. During solidification the volume of wax decreased, resulting in the top face of the solid cube, that had been left open to the air during cooling, displaying a significant concave surface with a central depth of 2.4cm. The remaining five faces of the cube that had cooled in contact with the aluminium were flat and at 90° to each other an all the 12 edges of the cube were straight and complete.

In order to mitigate against the shrinkage and produce an accurate 4cm cube of solid wax, white beads of paraffin wax were placed inside a Pyrex beaker and heated until liquid. A small amount of the liquid was then poured into the aluminium mould to a depth of 2mm. This wax was allowed to cool before a second layer of equal depth was poured on top and allowed to cool. This process was repeated until the last cooled layer was flush with the top of the mould. Once cooled, this resulted in a solid cube of paraffin wax of even dimensions with no concavity on any surface.

Instances of Encounter

In this encounter two cubes of solid paraffin wax were presented side by side to the visitor. As previously explained, they are made from the same material but do not have the same volumes; one material-object is a perfect 4cm cube, whilst the other has a concave dip in one surface. This latter cube therefore represents a 4cm cube of *liquid* wax. No labels declared the material from which the cubes were made, nor why they were of differing dimensions. The visitor was invited to pick up each cube, examining it both visually and haptically, as part of their materials identification process and investigation into the materiality of the form.

Responses and Observations

In every case of encounter, upon discovering the difference in volume the visitor expressed surprise at the discovery as well as some confusion, due to the apparent break in the isomorphic principle of the constancy of form. Occasionally this prompted questions as to the reason for the inclusion of the 'shrinkage affected' cube in the collection. Many, upon discussing and speculating on the processes and methods used to make the cubes, correctly surmised that the shrinkage affected cube represents a 4cm cube of liquid wax, and that the difference in solid volume between the two cubes shows the difference in volume occupied by the same molecules in their liquid and solid states. In other words, the relationship between material volume and material state, was revealed. Discussions then followed on whether the shrinkage affected cube should really be included in the library and how liquids in general might be described both from a scientific perspective but also also how they can be represented in a materials library.

Many found it easy to correctly identify the cubes as wax once they had picked them up due to the tactile recognition associated with the oily feel and the ease with which a finger nail could be dug into the surface. On closer inspection of the 'perfect' paraffin wax cube, the strata caused by the layered casting method was both seen and felt by visitors and in some cases (31-08-07 for example, figure G.8) provoked discussions on casting methods and behaviours of materials when transforming form liquid to solid. These marks provided a clue to the process of the cube's formation, and revealed the mechanisms of manufacturing. This enabled comprehension of the need for difference processes of making due to the behaviours and properties of the material as it transforms from liquid to solid.

5.2.4 White Chocolate

This encounter focuses on the multi-sensory experience of materials identification and the specific use of the olfactory sense in this. The design of the encounter introduces a foodstuff as a material in the form of a white chocolate cube and enables the material to be shared and experienced socially. The effect of repeated encounter is then shown through material transformation, which in turn demonstrates specific properties of the material.

About the Material

Chocolate is a combination of cocoa solids and fats extracted from the seeds of the cacao tree and mixed with sugars and some times milk solids, to produce a material with distinct characteristics of colour, aroma and taste. Cocoa butter has an extremely low melting point, around 35°C, therefore making chocolate one of the few substances that melts at body temperature (37°C). White chocolate does not contain any cocoa solids and is simply a combination of cocoa fats (cocoa 'butter') with milk solids and sugar. In comparison with other chocolates, white chocolate is difficult to work with and heat due to the high levels of cocoa butter, for melting the material can result in the splitting of the cocoa butter (Smith, 1999).

To make the cube of white chocolate a number of bars of the material were gently melted in a bain-marie and then poured into the aluminium mould and left to cool. Once the chocolate had solidified a hot wire was drawn across the top of the mould to level off the cube before the mould was unscrewed and the cube released.

Instances of Encounter

In this encounter, the singular cube of white chocolate was presented to the visitor. No label giving information about the cube was provided, nor were specific acts of haptic investigation prohibited. Visitors were simply invited to attempt an identification of the material in any way they see fit. To this end, two main modes of encounter can be identified; the first involving a singular investigating visitor and second involving two or more visitors who may or may not have known each other prior to the encounter.

The first instance of encounter began with the visitor visually studying the material, noting the colour, sheen and subtler elements of form. Next the visitor picked up the cube, and began to haptically investigate the material, feeling the texture of the surface, bringing it to their face in order to examine it more closely. At this point the visitor was able to smell the cube and bring it to their mouth to lick or nibble if they so desired.

The second instance, follows the pattern of behaviours laid down in the first instance but with one major point of difference, that of the inclusion of more people. After one of the visitors had encountered the cube to their satisfaction, they would pass it onto the next visitor and so on, depending on the number of people present and wishing to experience the material. Visitors usually watched each other performing varying acts of haptic enquiry (handling, stroking, squeezing, prodding) and either mimic these when it was their turn, or invent new, untried modes of encounter. On a number of occasions, a visitor who smells the cube would then exclaim they know what the material was and proceed to place it under the nose of others, occasionally in a forcefully exuberant manner. Thus the length of time each visitor spent handling the cube varied and the tasks they performed changed as encounter is performed and recounted to the group and experiences shared and accumulated.

Responses and Observations

When initially encountering the cube of white chocolate and examining it simply by sight, many visitors were unwilling to commit to an identification of the material. Most concluded that is may be some form of wax, soap or white chocolate, taking as their cue for materials identification the colour and general appearance of the material, but expressed the distinct feeling of not being sure. Some noticed the slightly rounded corners of the cube and deduced the material was probably fairly soft but did not suggest the cube was made from anything in particular as a result. This suggests that whilst the visual mechanism for materials identification is highly attuned and many degrees in the subtleties of form and material properties can be perceived, the mechanism is also limited.

In the first moments of handling the cube, the assumptions made through visual examination were not substantially challenged. Visitors noted the smooth feel of the materials and the way in which a residue of it could be perceived as remaining on the finger tips, but visitors were not much better placed to differentiate between a wax, soap or white chocolate.

Very swiftly after the initial picking up of the cube, visitors would bring it up to their face and smell the material. At this moment, the successful identification of the material was unanimously achieved. Many would exclaim their delight and pleasure at the smell and evocations it produced, whilst a few were compelled to place the tip of the tongue against the cube and taste the chocolate. This practice was more readily undertaken nearer the beginning of the life of the cube, when its appearance was less battered. If a fresh cube of white chocolate was produced for each visitor/encounter, possibly produced from out of some form of wrapping, it is plausible to assume that more visitors would have been willing to taste the cube and perhaps even eat some, if not all, of the material.

Experiences gained in the second instance of encounter, where more than one investigating visitor was present, were similar to those of the singular visitor outlined above but with two distinct differences. First, as with the glass cube, the repeated handling and passing around of the cubes by a number of people meant that the cube warmed up through repeated and prolonged contact with human hands. Due to the extremely low melting point of white chocolate, this mass handling had a direct impact upon that which was being handled as the cube of white chocolate began to soften and melt. The previous residues of oils felt by visitors in the first instance were now more palpable traces of melted chocolate, resulting in an increased form of physical encounter with the cube and thus an advanced sense of the cube's materiality. Whilst the impact of this handling can be seen as damaging the cube, it must also be appreciated that it is an inevitable result of this mode of material enquiry and serves as a clear illustrator of the specific material's properties and behaviours, when in particular environmental conditions, and subject to specific activities.

Like many of the encounters with cubes involving multiple visitors, it is impossible to ignore the impact of the actions and comments of people upon each other during the task of materials identification and recognition. The reactions of one visitor feed onto the actions, assumptions and experience of another, who is not only testing their own conceptions but measuring them against those of others to form affirmed conclusions. If one visitor witnesses another specifically smelling the cube and exclaiming it to be white chocolate, the second visitor will be more likely to smell the cube rather than attempt any other form of examination, in order confirm or deny the discovery of the first. In the case of encounters involving more than one visitor, the actions that illicit the clearest responses with regard to the identification of the material become the actions most repeated.

In every case of the cube being successfully identified as white chocolate, be it the finding of the individual or the collective agreement of a group, olfactory examination proved to be the most reliable and powerful tool for such identification. Any damage incurred by the handling and occasional tasting of the cube served to highlight specific characteristics of the material and its behaviours, thus advancing the understanding of the matter by the executor of the damage.

5.2.5 Aerogel

The design of this encounter, and specifically the selection of the material used to make the cube, demonstrate the ability of materials to generate surprise and wonder through the physical experience of them. This final instance of material-object encounter draws attention to the affects the act of physical encounter has upon the material from which the cube is made, as well as the conceptual effects materials can have upon those who experience them.

About the Material

Silica aerogel is made from a silica sol-gel from which the liquid solvent has been removed through a process of super-critical drying using an autoclave (JPL, 2002). The result of this process is the creation of a highly porous solid with an extremely low density. By controlling the concentration of silica in the gel, it is possible to make a silica aerogel with a density of 1.9 mg/cm^3 that at 99.8% air, is the lightest solid in the world (JPL, 2002). Silica aerogel is also an excellent thermal insulator both materially, as silica is a poor thermal conductor, and structurally, as the lattice of material pores prevent the ready convection of air through it. Although its strength to weight ratio is impressive (can easily support loads of up to 1,000 times its own weight), aerogel is fragile in the hand and extremely friable. The characteristic blue appearance of the material is due to the specific index at which the fine pores of the material's structure scatters light, rather than an innate colouring or pigmentation of the material. Other materials can be formed into aerogels, for example carbon, which makes for black aerogel.

The Jet Propulsion Laboratory at NASA developed this particular ultra light-weight silica aerogel as the material solution for the Stardust project –an attempt to capture particles of interstellar comet debris and bring them back to Earth for analysis. To generate images for analysis, automated microscopes scanned the aerogel, generating movies compiled from frames of horizontal slices that moved vertically through the material. These movies were then uploaded to the Virtual Microscope of the Stardust project website for registered users to systematically trawl through and hunt for the track marks of particles captured in the aerogel

A 4cm cube of silica aerogel was made by Steve Jones at the Jet Propulsion Laboratory. In order to create a cube of the required dimensions a number of test cubes were made to calculate the degree of shrinkage that would occur, enabling a specific mould to be made that factored in the shrinkage in form.

Instances of Encounter

An archetypal brass balance was presented to the visitor. On one side sat the cube of aerogel whilst the other was empty but the scales were level. The visitor was not asked to perform a task of material identification, instead they are told a little of the material origins, uses and properties, specifically that it is the lightest solid in the world. The material was offered to them to hold. If the offer was accepted (as it was in the vast majority of cases), the visitor is instructed to hold out their hand with their palm facing up and be careful, for the material is delicate. The cube is then placed into the upturned hand of the visitor.

Upon holding the cube, many visitors bring it up to their face and visually examinined it more closely, perhaps peering through it at an available light source to see how the material changes as the incident of the light passing through it changes. Some visitors tentatively place one finger on the top side of the cube and press down, whilst others occasionally squeeze it between their thumb and forefinger. In cases where more than one visitor is engaged in the encounter, the visitor holding the cube may lift it up and present it on their palm for the other visitors observe, before it is passed on the them to hold if they so wish.

Responses and Observations

The apparatus used to present the cubes clearly connotes that there is something significant in the mass of the material. Assuming the scales are not rigged in some way, the visitor can deduce that what they are looking at must be very light –a conclusion that is drawn without having to lift the material. Due to the delicate nature of aerogel, this staging devise acts as a form of physical barrier, protecting the cube from carefree lifting and indelicate actions of visitors, as well as a semiotic safeguard, signifying that this is a material that if one were to touch, should probably be treated with care.

On visually encountering the cube of aerogel, the vast majority of visitors marvel at its appearance, unable to fathom the nature of the material they are looking at. Many begin to try and verbally describe what it looks like, suggesting a "hologram", "blue smoke", or "solid sky".

On holding the cube, visitors exclaim amazement at not 'really' being able to feel the cube as it sits in the palm of their hand; "wow, it's like a hologram" (19-06-07), "it's not really there" (10-05-08), "are you sure this is a solid?" (14-08-09). They often held the aerogel up to their face as if trying to look inside it or get a closer view of that which was not quite visible or somehow out of focus. At this point some visitors would ask if the cube was solid and/or why the material appeared blue. They observed that when they held the aerogel up to the light, it changed to a yellowish colour and were curious to know what phenomena was at play. Some visitors were happy to hold and visually examine the aerogel like this and experience the absence of mass before having the material returned to the balance scales. The delicate presence of the aerogel cube, both visually and physically, induces a great sense of care in the part of the visitor and they adjust their behaviour accordingly, adopting a limited mode of haptic engagement. The majority of other visitors were more haptically curious and proceeded to make future investigations into the material.

Many visitors needed to touch the cube of aerogel with the fingers of one hand as it sat in the palm of the other. The action was generally executed with care but was never the less intended to test the resistance of the material; is if making sure it were really there and checking its solidity by poking or grasping the cube in some way. If the visitor was not careful, this could cause the material to fragment or shatter. Occasionally small amounts of the material were chipped of at the edges of the cube but a full scale fragmentation of the form has so far been avoided. If this did happen, the amount of material available for the next visitor to experience would be diminished. If it were to happen repeatedly, there would no longer be any aerogel left for people to encounter. With regard to the accumulation of material knowledge through an experiential encounter with matter, the damaging of the cube in such a way would afford the visitor who caused the damage a unique form of materials knowledge, beyond that of any prior visitor.

Every visitor who handled the cube of aerogel came away form the encounter with a residue of aerogel upon any area of their skin that was in contact with the material, with reports of a fine dusty feeling in the palm of the hand or on the tips of the fingers commonplace. Whilst many noticed the residue of aerogel left upon their hands, few remarked upon the residues they left on the aerogel. Tiny particles of dead skin, secreted oils and sweated salts are all present upon the surface of skin and get trapped and then lifted away by the fine pores of the aerogel when it comes into contact with the skin. Over time the build up of these skin cells, oils and salts leave a visible white residue on the surface of the aerogel and are impossible to remove without removing some of the body of the material.

Very occasionally a visitor would decline from holding the cube of aerogel alltogether, citing an inability to trust themselves not to drop it or damage it in some way as their reason for not wanting to handle the cube. The precious nature of what they see, appears to provoke a reverent caution in the visitor who is content to simply gaze upon the material. Although this reaction is rare, it is more often seen coming from a visitor who is part of a larger group and takes the position of witness, observing the actions of others and the material, commenting upon it and asking questions, but not handling the cube for themselves.

Visitors encountering aerogel in groups of two or more experience much the same encounter as the singular inquiring visitor. The same modes of materials enquiry are employed and the same sense of wonder, delight and amazement is felt by all. The difference with the group encounter is, once again, that the visitors are able to share their thoughts with each other, offering a collective appreciation and affirmation of experience. In nearly every case however, there is little that one visitor can do to distract or detract from the experience of another, short of destroying the cube. The encountering of the cube of aerogel by a visitor, be it as a part of a group or as a lone investigator, becomes an individual experience, the moment when they and they alone met the lightest solid in the world.

5.3 Reflections

From the specific material encounters discussed in section 5.2, a number of common themes emerge. This section offers a synthesised discussion of these themes and the way in which the analysis of specific cubes enhances the reading of the entire cube collection.

5.3.1 Haptics

Every case of encounter discussed involved a multi-sensory experience: initial visual appraisals led to touching in the form of lifting, holding, stroking, squeezing or prodding. In some cases this haptic exploration continued in the form of tasting and smelling, where an intimate touching of the tongue and a bringing to the nose, afford further methods of sensory perception. Each of these manual responses arose from the impulse of enquiry on the part of the visitor, attempting to discover more about the cubes. The deliberate enabling and embracing of this haptic mode of materials enquiry lies at the heart of the methodology of staging material-objects as cubes and the notion of the encounter.

> **haptic • adj. 1** of, pertaining to, or relating to the sense of touch, in particular relating to the perception and manipulation of objects using the senses of touch and proprioception.
>
> –DERIVATIVES **haptically** adv. –ORIGIN Late $C19^th$: from Gr. *haptikos* 'able to touch or grasp'. (OED, 1999)

The haptic is by definition, different to the sense of sight, and provides information not accessible by seeing. The glass and acrylic cube appear nearly identical and it is not until the cubes are handled that visitors discover differences between them, such as their apparently different temperatures (due to their different thermal conductivity), which enabled visitors to correctly identify the materials (see subsection 5.2.2). The aluminium and tungsten cubes also appear visually similar but on lifting, the stark difference in the masses of the cubes is revealed (see subsection 5.2.1).

The revelation of material properties (in this instance masses and thermal conductivity) through haptic enquiry is a physical discovery that is first understood experientially as a phenomenological event, where perceptions of matter and its specific properties are generated through direct experience of them. Within the act of lifting and holding a cube, the body is mediated by the material-object, shifting and adjusting actions and movements to react to, and compensate for, the properties and behaviours of the material. In each case, the handling of the cube initiates physiological responses that yield a form of material knowledge.

A number of physiological studies have been undertaken on different human subjects, testing the limitation of their sensory perception. In relation to the lifting and perception of mass, Cole and Sedgwick (Cole, 1992) investigated the perception of forces, Bard and Fleury (Fleury, 1995) studied the judgement of weight, and most recently Anderson and Wallace (Wallace, 2002) conducted experiments that tested the ability of an amputee to discriminate between weights lifted with their prosthetic arm. With regard to an ability to accurately judge the weight of an object lifted by the hand and arm, perceptions "depend on both peripheral (sensory) and central (motor) influences" and that sensory information is gathered from a variety of sources, "including cutaneous, mechanoreceptors and proprioceptors located in the hand and arm" (Wallace, 2002). Cutaneous, mechanoreceptors and proprioceptors are types of sensory receptors embedded in the skin that respond to mechanical pressures and deformations, sending signals to the brain about the forces have been applied. "These receptors provide information about the friction and pressure exerted by the object on the skin and about the forces generated by the muscles and joints to lift the object against gravity" (Wallace, 2002), thus enabling the physical perception of the object and judgement of its mass, crucial mechanisms for the encountering of the cubes, especially those of tungsten and aluminium.

Phenomenologically speaking, physiological mechanisms may be influenced by things outside of the territory of haptics and thus the visitors' ability to perceive the materiality of the cubes. Anderson and Wallace remind us that "other sources of sensory information, such as visual cues, may also contribute to one's ability to estimate the weight of a hand-held object" (Wallace, 2002).

John F. Bannan writes on the phenomenologist Merleau-Ponty and states that for Merleau-Ponty, 'the tactile situation' is akin to the act of seeing and its relationship to light, where "we do not see it [light], but rather we see according to it (Bannan, 1967, p104). In the act of touching, Merleau-Ponty believes there to be tactile constants, in the same way as light is a constant for the act of seeing. An example of a tactile constant for Merleau-Ponty would be "a given weight" for this is "judged the same whether lifted by hand, head, foot, or teeth" (Bannan, 1967, p105). This constancy enables the body to be present as a "fundamental power of transfer and equivalence in which the unity demanded by this constancy is somehow accomplished. Actually, body movement serves touch as illumination serves vision. (Bannan, 1967, p105) In other words, the body is a tool for the measurement of experience and in touching, reveals what is touchable. In relation to the cube of aerogel, this ability to touch the material, and in doing so reveal it, is clearly evident: when the cube of aerogel is placed in the palm of the visitor's hand, the visitor still feels the need check that it is really there, prodding the material and checking the nature of its solidity

The contrast between the lightness and heaviness of the aluminium and tungsten cubes respectively is a surprisingly powerful experience for many visitors, partly because the two cubes are initially perceived as almost identical. In contrast, the weight of the aerogel cube is less readily expressed and even felt. This may be due to the overwhelming visual power of the material, but it may also be due to the lack of tactile constancy and "a given weight" with which to calibrate the experience. One of the reasons the material is so visually captivating is that there literally is nothing like it, but also interferes with perceiving the lightness of the material, *the* lightest solid material a visitor is ever likely to hold. If the visitor were to hold a polystyrene cube in one hand and the aerogel cube in the other, this may go some way to enhancing the perception of the lightness of the aerogel as polystyrene is a material that is culturally understood as light.

In his 1948 essay on the "Imagination of Matter", *Earth and Reveries of Will*, the philosopher of science Gaston Bachelard wrote that; "To recover those powers through which the becoming of minerals is imagined, it is necessary at the very least to experience the physiology of these utensils, not merely be amused by their shapes" (Bachelard, 1948, p182). Like Merleau-Ponty, Bachelard agreed that physical experience was central to the knowing of matter, a knowing that enabled creation and transformation of matter to matter, to form and to object. To simply look at the cubes and appreciate their equal volumes is merely being 'amused by their shape'. To look at the cubes and pursue haptic modes of enquiry is to take a step towards the appreciation of the material in relation to its properties, and thus its position within the nexus of materiality.

5.3.2 Damage

Haptic methods of enquiry, by their very definition, involve the physical coming together of material-objects (cubes) and visitors. As recognised by the modes of display in traditional museums, the practice of physically experiencing an item will result, to varying degrees, in the damage of the item in question. The Victoria and Albert Museum, like many homes for national and international object collections, aim to best conserve the items under their care and acknowledge that "although it is a natural response to want to touch things, the museum usually has to discourage this as the cumulative effects of abrasion, grease and sweat can result in irreparable damage" (V&A, 2008). In this context, the notion of damage is perceived as a negative occurrence; a counterpoint to the concept of preservation, inevitably to the detriment of the artefact and coinciding with its dictionary definition.

> **damage • n. 1** physical harm impairing the value, usefulness, or normal functioning of something. ▶ unwelcome and detrimental effects.
>
> –DERIVATIVES **damaging** adj. **damagingly** adv. –ORIGIN ME: from OFr. from *dam, damm* 'loss or damage', from L. *damnum* 'loss or hurt'. (OED, 1999)

The central dictum of forensic science is that "every contact leaves a trace" –a maxim attributed to the founding father of modern forensic science, Dr Edmond Locard. Also known as Locard's Exchange Principle, the idea confirms that in every act of contact between a human and a human, or a human and 'thing' (which may be considered here as an artefact, cube, or material-object), the human leaves behind a trace of themselves in a mutual act of cross contamination (Chisum and Turvey, 2000). Such traces are then regarded as physical evidence that can be used to construct a better understanding of an event or series of events, prove occurrences and establish links between an action and the perpetrator of the action.

In discussion on actions leaving traces within a criminal context, in which a forensic examination is most usually employed, professor Paul Kirk asserts that:

> "Wherever he [the criminal] steps, whatever he touches, whatever he leaves, even unconsciously, will serve as silent witness against him. Not only his fingerprints or his footprints, but his hair, the fibres from his clothing, the glass he breaks, the tool mark he leaves, the paint he scratches, the blood or semen he deposits or collects." (Kirk, 1974)

In doing so, Kirk outlines the broad nature of that which can be regarded as a trace. It is clear to see however that many of the forms of traces can also be regarded as forms of damage; for example the broken glass window, the scratched paint work and the fluid stains Kirk alludes to. Kirk also affirms that traces are left by the physical presence of the criminal though the action of stepping and touching, demonstrating physical presence as key to the creation of the traces and thus the damage. This relationship of forensic science to damage serves as a reminder that one person's damage is another person's physical material evidence, it simply depends on the point of view from which the evidence is regarded.

That which constitutes a trace may be visible to the naked eye or alternatively perceived with the aid of varying technologies and techniques; simple magnification devices like magnifying glasses and portable microscopes are used to view samples at the microscopic scale, ultraviolet lights are used in dark environments to illuminate fluorescent matter, and specific powders are used to tag and reveal trace elements like oils deposited by skin. Once perceived and retrieved, samples are subjected to various modes of analysis in order to determine the origin of the trace; for example, DNA screening.

With regard to the cubes, the concepts of both forensic traces and physical damage are relevant when reflecting upon the specificity of the encounters and the generality of the cubes as a collection. As the haptic mode of materials enquiry is central to the methodology of materials discovery within the encounter, the physical exploration of the cubes is encouraged. However, this situation will inevitably result in a certain degree of damage being done to the cubes, therefore it is important to embrace the concept of damage and foreground it as evidence of encounter and revelatory agent of materiality.

The relative fragility of the aerogel cube marks it out as a material that is readily susceptible to damage. Though relative to its density aerogel is strong in compression, the material is nevertheless friable and prone to shattering on handling since it is only 0.2% solid. Particular care must be taken not to apply compressive forces through the act of closing the hand around the cube as this results in the material crumbling and shattering. Shearing forces, where the hand or fingers move across the surface of the aerogel can also cause damage to the material, with small particles of the material being worn away. If one strokes the surface of the cube and then rubs ones fingers together, these eroded particles can be felt between the fingers. (For a full description of the nature of this case, see subsection 5.2.5.)

Not only does the aerogel leave a trace upon the hand of the person who touches it in the form of the fine eroded particles, but the person who touches it also leaves a trace upon the aerogel. On close examination, residue of skin cells, sweated salts and oils are evident on the surface of the cube, causing a white discolouration as the structure of the material is no longer able to refract the light at the same index as before contamination. Figure 5.4 shows

Figure 5.4: The aerogel cube displaying areas of white discolouration due to residues of oils, sweated salts and deposited skin cells on its surface, accrued from being held.

the aerogel cube against a black background, enabling the white areas of discolouration to be easily seen. The act of touching has left tangible evidence; the aerogel acts a palpable forensic materials, capturing the DNA of those who have handled it and shifting its properties to signify an encounter has occurred.

Although less immediately evident, examination of other materials at different scales will also reveal damage caused by human encounter. In the case of the sugar and salt cubes, whist the handling of the cube may dislodge grain of the material and alter the cubes appearance at the macro scale, the act of tasting dissolves microscopic amounts of the material, altering the volume of the cube if measured with microscopic accuracy. The tasting leaves traces of the taster's saliva, revealing sugar and salt to also be forensic materials when examined at the correct scale of magnification.

With regard to the cube of copper, print marks from the skin of the visitor cause the material to oxidise and discolouration to occur on the surface of the material. Atmospheric moisture contribute to this process and the a cube which was once bright and shiny becomes dark and dull. It is possible to return the bright appearance to the cube but this would involve the rubbing away of a tiny layer of the material through the act of cleaning. Over time, this removal would visibly alter the volume of the cube and thus the desired dimensions of the material-object.

The form of a cube, when viewed mechanically, offers specific stress concentrators such as the corners and the edges of the cube, and it is these features of a cube that are most prone to damage. The occurrence and examination of such damage has implications for the status of each material-object as 'cube' due to the impact of this damage on the dimensionality of the form. In other words, if the corner of a cube is broken off or chipped away, the form is no longer that of a perfect cube.

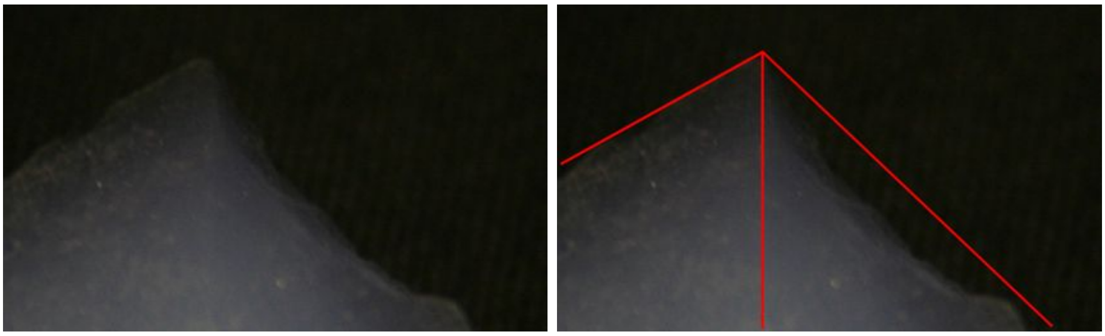

Figure 5.5: The aerogel cube displaying signs of damage along an edge that leads to one corner.

The vulnerability of the corners and edges of a cube can be clearly seen with the aerogel cube as this material is highly friable, thus prone to shattering and chipping under stress. Figure 5.5 shows one corner, three edges and two planes of the aerogel cube. The left hand image is duplicated on the right with the addition of red lines to indicate where the former edges of the cube. The loss of material along these edges is due to the friable nature of areogel and the effects of handling upon it. As pieces of the aerogel break away, the dimensions that previously defined the object as a cube (twelve edges of 4cm length, six faces of 4cm^2, eight corners of 90°) are challenged.

Figure 5.6: The cube of white chocolate, after being eaten by mice.

A clear example of a cube that has received an overt form of damage, dramatically shifting its dimensions, is the cube of white chocolate. On the morning of the 8th of October 2007, the white chocolate cube was discovered to have been partially eaten by mice. The other edible cubes (the milk chocolate, dark chocolate and jelly cubes) did not display signs of having been eaten, suggesting the stronger aroma and sweetness of the white chocolate combined to produce a more alluring foodstuff.

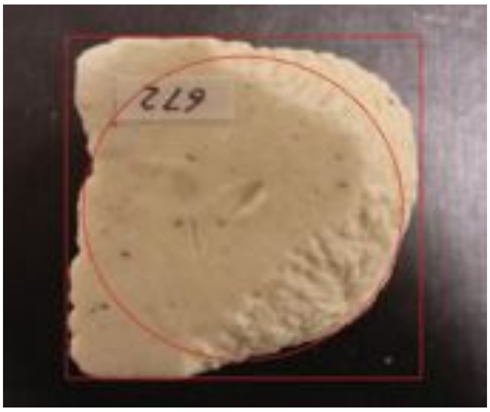

Figure 5.7: An illustration of the shifting dimensionality of the cube of white chocolate, from cube to sphere.

Figure 5.6 shows the white chocolate cube from two different view points, illustrating the new dimensions of the material-object and the teeth marks left upon it. With consideration of the weak points of the original form (the corners and the edges), it is clear that these are the areas that have been attacked first. To eat away the corners and along the edges is simply to employ the most efficient mode of attack upon the given form. To have eaten a hole out of the centre of one of the faces of the cube would have been extremely unlikely, not to mention mechanically difficult to achieve.

The shift in the dimensionality of the white chocolate cube is so dramatic that the form of the cube can be perceived as changing into that of a sphere. Figure 5.7 illustrates the morphology of the form in two dimensions and shows not only where the edges of the material-object once were, but where the circular form is emerging.

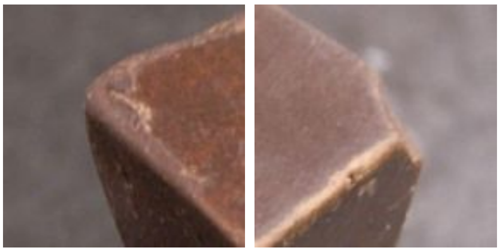

Figure 5.8: Two of the corners from the cube of dark chocolate. One corner shows signs of ‘rounding’, whilst the other has been chipped.

Although the cube of white chocolate is the most dramatic example of the evolution of a cube to a sphere as the result of encounter, other cubes in the collection display signs of a similar behaviour of form and material. Examination of the dark chocolate cube reveals damage to its corners has occurred in two distinct ways. As shown in figure 5.8, one corner of the dark chocolate cube has been chipped off, whilst the other has been smoothed and rounded down. Each of these methods of material manipulation (removal or remoulding) can result in the creation of a sphere from a cube, but each speaks of a different form of encounter.

Figure 5.9: Left: cube of blu-tack. Right: cube of plasticine.

The cubes of blu-tack and plasticine, as shown in figure 5.9, display clear evidence of the morphing of the cube to the sphere as the result of handling. The corners of both cubes are gradually rounding off, literally turning into spheres as the direct result of the action of handling and the nature of the materials. Both cubes have accumulated residues on their surfaces, picking up dust, dirt and fluff due to the sticky nature of the materials. In the case of blu-tack, this property is a desired characteristic that enables its utilisation as a temporary adhesive, sticking things to other things.

The cube of aviation grade styrene foam (see figure 5.10) has one corner that appears, on first glance, to have been chipped off. On closer examination it is revealed that the corner has in fact crumpled into itself and become compacted. An circular depression is also apparent on the top face of the cube. The fact that this damage exists is due to the nature of the material and the actions of a visitor within an instance of encounter. From examination of this damage, it is possible to deduce information about the properties and behaviour of the material, as well as something about the behaviour of the visitor. The size and rounded concave appearance of the depression suggest it was made by a finger pressing into it, testing the materials solidity, as happened in the aerogel encounter.

Scales of time are also important for perceptions of damage and revelations of materiality. In the case of the chocolate cubes, there may be relatively immediate damage from any tasting, eating or chipping that may occur, but if the cubes are held in the hand for a prolonged period of time, a new form of damage occurs; the material begins to melt (see 5.2.4). As previously

Figure 5.10: 4cm cube of blue styrene foam, aviation grade. Displaying a depressed corner and finger print.

mentioned, chocolate is one of the few materials to melt a body temperature and as a result, would be one of the few cubes to change material sate from solid to liquid when held in the hand during an encounter. With this in mind, the concept of damage is further underlined as a process of materials revelation where the innate behaviours of a material are displayed through touch. In this instance therefore, it is possible to argue that the chocolate is not damaged but simply behaving as it should in the environmental conditions it finds itself.

The form of the cube lends itself to a particular type of deformation due to the concentration of stresses at the corners and edges. At these points, as has been revealed and discussed, materials are liable to to chip or become rounded, depending on the properties of the material in question. The type of damage incurred has been shown to be due to the relationship between the form and materiality of the cube and thus foreground the assurance and examination of damage as key to the concept of the encounter as an act of material revelation.

The connotations of damage as a negative occurrence is challenge by the methodology of encounter. If the most important aspect of the cubes is simply their presence as a set of perfectly isomorphic material-objects, then the handling of them is not important and should be prohibited. However, handling is positively encouraged, as the *experience* of the set is deemed more important than its preservation. It has already been established that physical touching lies at the heart of the concept of the encounter. In most cases it is this touching that acts as the primary agent of damage, and as damage is a way of displaying and revealing materiality, handling is a primary agent of materials revelation. Damage is a form of evidence that signifies encounter and an agent of materials revelation.

5.3.3 Taxonomy

> **taxonomy • n. 1** chiefly Biology the branch of science concerned with classification ▶ a scheme of classification.
>
> –DERIVATIVES **taxonomic** adj. **taxonomical** adj. **taxonomically** adv. **taxonomist** n.
>
> –ORIGIN C19: coined in Fr. from Gk *taxis* 'arrangement' + *-nomia* 'distribution'.
>
> (OED, 1999)

When an instance of materials revelation has occurred, be it that a specific cube possess an especially heavy mass, a sweet taste or crumbly edge, the information gained acts as both a crude method of materials identification and a starting point for materials classification, where other cubes can be judged in relation to their status as more or less like the previous cube. In practical terms, the other cubes in the collection can be measured similarly by the handler and rated relatively, according to the perceptions of the individual. The knowledge gained by encountering a specific cube or set of cubes, enables an evaluation of all the other cubes, in the light of the knowledge gained through the initial encounter.

The staging of an encounter with the cubes of aluminium and tungsten acts as a platform for the performance of mass and a starting point for the interrogation of all the cubes in relation to their relative weights. Subtleties begin to be detected, similarities and differences noted, and connections drawn: within a taxonomy of mass, oak and aluminium sit more closely together than tungsten and aluminium. It would be possible for visitors to arrange the cubes in order of mass, from the lightest to the heaviest/heaviest to the lightest, with the tungsten cube at one end and the aerogel cube at the other, enabling a visual representation of the phenomenological experience of lifting the cubes and computing of their mass. Although this was not an instructed task, a number of visitor expressed a desire to do just this and attempted to order some of the metallic and wooden cubes.

If an ordering of the cubes by weight was instructed, a record could be taken of the 'line-ups' visitors create through a haptic enquiry into the mass of the cube. This document could be compared to the correct order of the cubes masses as recorded in tables 5.1, enabling a post-encounter evaluation of the successes and failures of the haptic method of weight discrimination. It would also be possible to ascertain if mass was judged more or less correctly for different materials and whether this accuracy fitted with the presence of any other material properties out side of mass, like thermal conductivity. Such a document could be an area for future work where encounters with the cubes were presented as more formal experiments rather than as part of an over all experience whilst visiting the Materials Library.

Other haptically and visually led material taxonomies could equally be employed, grouping cubes in relation to their thermal conductivity, perceived harness or softness, smoothness, fragility, colour, shininess or even the degrees of 'cubeness'[1], to name but a few. Whilst unconventional, these categories are not wholly arbitrary. Conventional material taxonomies would offer the categories of woods, metals, glasses, ceramics and polymers as broad ways of differentiating matter and its properties. Experience of specific properties however may find correlation between materials that would otherwise have been considered disparate if the only analysis of them was to consider the category of material to which they belonged. Discovering non considered alignments between materials is all part of the outcomes of the encounters.

The classic material science categorisation of materials is fundamentally related to the chemistry of matter and thus all the known elements in our universe that are mapped on the periodic table (see sections 2.1, 2.2.1 and figure 2.1). Geoffrey Bowker and Susan Leigh Star declare in their book *Sorting Things Out*;

> A constant finding of the history of science is that there is no such thing as a natural or universal classification system. Classifications that appear natural, eloquent and homogeneous within a given human context, appear forced and heterogeneous outside of that context. (Bowker and Star, 2000)

This suggests even the established and accepted paradigms of material science is nevertheless specific to the context in which it operates. The way in which things are perceived through and within the context of a physical encounter may therefore generate different categories based on the haptic knowledge of them, rather than their conceptual position in the periodic table, or on a specific materials engineering data sheet.

The ability to create, conceive and arrange new taxonomical systems for the cubes brings new frames for the perception of and discrimination of the cubes, between materials and towards the material-object. The making of complex relative discoveries enables the creation of multiple taxonomies that embrace nuances of individual perception, whilst establishing a diversity of categories for the presentation of the cubes; multiple, conjoined and simultaneous taxonomies that can be both physical and/or conceptual.

5.3.4 The Librarian

Within the context of the Materials Library, the author of this thesis is the materials library. Within instance of encounter, the role of the materials librarian is ostensibly three fold. Firstly

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[1] The term *cubeness* has be coined here to describe an expression of a specific dimensionality of an object agreed to be a cube, though it can be more or less perfect mathematically.

the librarian is the host, facilitating and staging the encounter with and through the material-objects. They act as an instructor, introducing specific cubes to the visitor and inviting them to perform specific actions or tasks of material identification. This role also involves the librarian asking questions of the visitor in order to tease out responses to and (often latent) knowledge of the materials from the visitor. The second role adopted by the librarian is that of the consistent observer of encounters. In this role, the librarian acts as the witness of both the behaviours of the visitors and the types of actions they perform, and the behaviours of the material-object. For example, the librarian notices visitors gently squeezing the plasticine cube and later notices the rounding of the corners of the same cube. From the observations the librarian draws conclusions that inform the next encounter, establishing modes of repeatable presentation, constancy of evaluation and the creation of what might be considered the ‘best practice’ for an encounter. In the light of the methodological considerations outlined in section 4.1.2, it is clear that this aspect of the librarian’s role draws heavily upon anthropological and ethnographic methods of reflective observation (Davies, 2008), field work (Burgess, 1984) (Emerson et al., 1995) and participatory action researcher (Spradley, 1980) (MacIsaac, 1996). The third role for the librarian is that of the embodiment of materials knowledge. Whilst this role feeds back into the previous two through virtue of being cumulative and actively fed at every step of encounter (from the setting the scene, through to the event of visitor interaction, to the aftermath of examining material damage), the librarian demonstrates the position of knowledge bearer by answering questions from the visitors, recounting stories about the materials to the visitors and receiving stories about the material *from* the visitors.

The fact that visitors offer up information, knowledge and stories about specific materials is a key outcome of the encounters. The prior knowledge of the visitor, whilst un-quantifiable, has a qualitative effect upon their encounter. Many visitors have specific material knowledge as the result of their job, training, interests or practice. They may equally have a specific approach to the subject of material that frames the manner in which they explore the material-objects. A musician, for example may be familiar with materials like brass and wood, identify their cubes and provide an account of their use in their domain, but they may also interrogate every cube by lifting it to their ear and tapping it with their fingernail in order to register the sound it makes.

5.3.5 Concluding Remarks

Even if a visitor claims not to have a specialist knowledge, they will certainly have prior cultural knowledge of materials. Whether they are consciously aware of the extent of this knowledge, is another matter. In the case of the successful identification of the glass cube in subsection 5.2.2, prior knowledge of the material within a cultural context was crucial. The fact that the coolness of the material was recognised as a sensation to be associated with glass, is the result of previous encounters with glass that any supplier of double glazing would be happy to embrace. Accrued haptic experience of handling glass in daily life enables the accumulation of embedded memories of the sensation of touching the material and they way in which it responds to touch. As a result, within the setting of the encounter, this form of sensual memory transforms into material knowledge that can be brought to bear on the task of materials identification.

In each encounter, the acquisition of new material knowledge is a common outcome. Through having a novel experience with a material that a visitor may or may not have met before, the visitor expresses surprise, delight, intrigue and wonder. With this in mind, the position of prior ignorance must be regarded as equally relevant to the encounter as the position of prior knowledge. Peter de Bolla argues in his book *Art Matters* that wonder is a key component for learning and that not knowing something is a bedfellow to wonder. He suggests that wonder comes before knowledge since "as Socrates remarked, the primary motivation of wonder, is the recognition of ignorance. Wonder requires us to acknowledge what we do not know or may never know, to acknowledge the limits of knowledge. It is, then, a different species of knowledge, a way of knowing that does not lead to certainties or truths about the world or the way things are" (de Bolla, 2001). It is clear to see therefore, that though wonder and associated feelings of delight, surprise and intrigue, the experience of an encounter can provide a foundation for the creation of material knowledge.

The central methodology of the collection of cubes is the constancy of the isomorphic principle; that each material-object will be of the same dimensions as the next, 4cm cube. The constancy of form enables the surveyor of the cubes to realise that what is being foregrounded is the material rather than object status. In turn, this enables what are often subtle nonconformities in the dimensionality of the cubes to be observed. The shifts in dimensionality, be they as the result of damage, the processes used to create the cube or the natural change in the state of the material due to its properties and performance in the environmental conditions it finds itself, act as agents of material revelation.

The cube is a simple form to specify and manufacture from a wide range of materials, using a broad selection of technologies and techniques. Identical spheres made from just such a variety of materials would have been a much more challenging task to make and for some materials, an impossibility. The specific dimensionality of the cube affords a particular relationship to damage due to the concentration of stresses at its corners and edges, offering the opportunity for chipping or rounding down. The selection of the 4cm dimension enabled the cube to be substantial enough to experience but able to be lifted by a single hand of a weak child or strong adult, fitting neatly into the palm of a hand. The cube is also a relatively abstract form with a particular mathematical symmetry and being one of the platonic solids makes it a central and essential part of geometry. This abstract status also applies to the cube as an object with little useful function, meaning that the encountering of a cube made from a particular material places materiality to the fore, over functionality, and perception of object status.

Whilst there are undoubtedly advantages in the use of the form of the cube as the template for the isomorphic principle, there are also disadvantages. Many of the aspects of the cubes that are regarded as positive, outlined above, can equally be perceived as negative. The propensity of cubes made from particular materials to be damaged during an encounter means that either the cube will eventually be no longer a cube, or that measures must be taken and prohibitions put in place that limit the ways in which a visitor can haptically engage with a cube, thus reducing the potency of, and reasoning for, the encounter.

It can be argued that the form of the cube is *too* abstract for some visitors, with the oblique lack of function meaning that there is little one can do with the cube other than hold it. It is as if there is not enough object status in the cubes and this prohibits some visitors from liking the materials to their experience of them in the world. Equally, the subtleties of the cubes may also be why the science of the material is never truly explored within the conjecture or any subsequent investigations into the cubes as a collection. Only the mass of material is revealed to the visitor without further guidance as only the action that reveals it (lifting) is readily achievable by the visitors.

As a collection of material-objects, there are limitations to the cubes that effect their ability to represent the science of materials. Whilst the encounters do offer the experience of mass, they do not draw out the nuances of the difference between mass and density. For this the variable of volume would need to be introduced by the creation of cubes made from different materials, with different volumes but equal masses, resulting in a set of cubes of different sizes but equal weight. The cubes do offer a way of experiencing specific materials that induces wonder and sensory pleasure in the visitor but the set does not perform more than mass and an opportunity of a taxonomic critique of matter. The ability of the encounter as a method to reveal haptic materiality is clear, though the specifics of the knowledge gained in an encounter is dependent upon the nature of the material-object.

Chapter 6

Tuning Forks

This chapter introduces the tuning fork as a material-object with specific acoustic characteristics that result from the specificity of its form and its material properties. An isomorphic set of tuning forks were devised and created in order to investigate the sound of materials and generate an experience with material-objects that demonstrate the role of materiality on object function. This chapter explores how the tuning forks reveal aspects of the performativity of materials, and operate as a swatch that facilitates the exploration of material stiffness, density and coefficient of loss.

Whilst the cubes demonstrated density, hardness and thermal conductivity, they are abstract in their form and present little in the way of clear functionality. The effect of changing materiality did alter the integrity and tolerances of the form but did little to demonstrate the functional effect of each of the material properties.

The potential of the tuning fork was identified as an object that, when used, demonstrates something of the fundamental physics of sound and vibration. The use of a tuning fork, or in other words its playing, is a relatively simple task, requiring minimal technique and no musicality. The correct sound is simply the fixed tone produced when the fork is struck and the prongs allowed to oscillate freely. Previous knowledge or experience of the tuning fork might come from its use as a aid to tuning musical instruments, its presence in school physics lessons as an object of demonstration, or as a tool in hearing evaluations. As an object, it has a greater function than cubes and thus embraces a greater degree of object status in terms of its potential standing on the material-object continuum.

The three principle factors that influence the production of sound by a tuning fork are the shape of the fork (form), the density (materiality) and elastic modulus (materiality) of the material from which the fork is made. The pitch of the note that a tuning fork produces is expressed as:

$$f \propto \frac{1}{l^2}\sqrt{\frac{AE}{\rho}} \tag{6.1}$$

Where f is the frequency of the fork, A is the cross-sectional area of the tuning fork (form), l is the length of the forks prongs (form), E is the elastic modulus of the material (materiality), and ρ is the density of the material (materiality) (Burleigh and Fuierer, 2005). All of the values of form are accessible and comprehendible at the human macro level of scale, whereas the materiality values are derived from a structural scale invisible to the eye. For instance, in the case of metals the density is typically determined by the atomic mass which determines the weight, and the crystal structure which determines how closely the atoms pack together. The elastic modulus (stiffness) of metals is determined by the electronic structure of the atoms and the type of bonding present. Using tuning forks to explore these invisible structures and properties is the theme of this chapter.

As equation 6.1 demonstrates, an increase in the length, l, of the fork prongs increases the amount of a material that needs to oscillate in order to produce the sound wave. As a result, the prongs move more slowly, with each oscillation compressing the air over a greater period of time, generating waves of lower frequency. This lower frequency is heard as a tone of a lower pitch, or in other words, a deeper note is produced. Therefore, a standard set of tuning forks produce a scale of notes by offering a range of sizes, whereas the shorter pronged forks produce the higher frequency notes and the longer pronged forks make the lower frequency notes.

Equation 6.1 also shows that changing the density or elastic modulus of the tuning fork material, will also change the pitch of the note produced. This is illustrated graphically in Ashby and Johnson's multidimensional scaling (MDS) map of acoustic properties (see figure 6.1) which plots acoustic pitch against acoustic brightness in relation to a wide range of materials. Acoustic brightness is a materials property that quantifies how much a material absorbs sounds. Bright materials, like brass, emit sounds for a long time, while the reverse is true of dull materials, like foams, which absorb sound strongly. It is not known what precisely determines these dampening effects, but the property is quantified by experimentally measuring a material's coefficient of loss, and it is this that is plotted on the y-axis of figure 6.1. The map shows the distribution of different types of materials in relation to their acoustic properties: materials close together on the map are predicted to behave similarly acoustically even if their are from a different family material such as metals, ceramics, natural materials and polymers. It is interesting to note

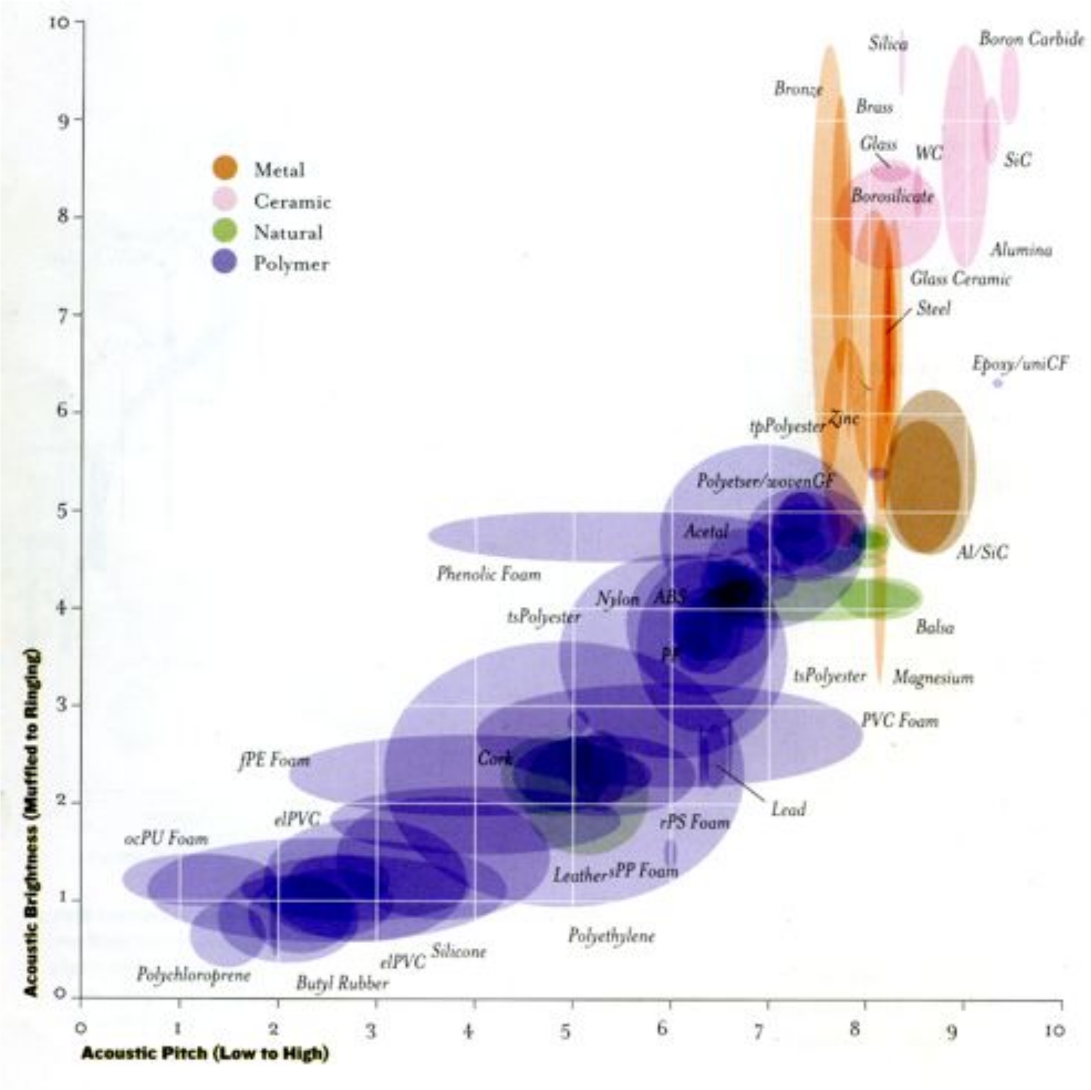

Figure 6.1: The Ashby and Johnson MDS map of acoustic properties used as a tool for materials selection (Ashby and Johnson, 2002, p.72).

that according to this MDS, the pitch of steel is within the range of pitches attributed to balsa wood, differentiated simply by the difference in acoustic brightness. With this in mind, the MDS offers a range of interesting material relationships that warrant closer examination in the form of rendering the material actual in the form of a tuning fork.

6.1 The Making

The creation of a set of tuning forks that keeps form constant and employs materiality as the variable, enables the exploration of the two values of the frequency equation (6.1) that are not altered in a standard commercial set of tuning forks; the values of density and elastic modulus.

Changes in material enables the resultant differences in the performance of the forks to be judged in relation to the micro property of density and performance of elastic modulus. Any shift in the frequency of sound produced by each fork will be a direct result of the materiality, rather than the form in which the material finds itself.

Two dominant types of form of tuning forks were identified: those with prongs of a cylindrical cross section and those with prongs of a rectangular cross section. To form a tuning fork in either of these shapes requires a variety of techniques and material manufacturing processes. Both forks of cylindrical and rectangular cross sections can be drawn and formed through the bending of rods of material with the required cross section dimension, where as a fork of rectangular cross section can also be machined from sheet and block material stock.

Figure 6.2: An image of the computer-aided design model of the John Walker 440Hz tuning fork generated to be an instruction for digitised manufacturing processes.

The fork with the prongs of rectangular cross section was selected as the master form as this shape lends itself to the more convenient manufacturing processes of machining, cutting and casting. The specific fork chosen as the model for this isomorphic material-object duplication was a John Walker 440Hz fork made from blued steel that produces the concert pitch note of ‘A’. A digitised three dimensional version of this fork was then produced using computer aided design (CAD) software, outputting a file that would act as a guide for computer aided manufacturing methods (see figure 6.2).

The thickness of the fork is 4mm throughout its length, meaning that a fork could be easily cut/machined from sheet materials available at 4mm thickness, or materials planed down to this thickness. The process of laser cutting was employed to cut out tuning forks from materials that would absorb the beam of high energy light and thus be melt or burnt away. The laser cutting facilities of the 4D Model Shop were employed for this task and their head technician Karl

Harris supervised the job of making tuning forks form the following materials: plywood, balsa wood, ironwood, bass, obeche, spruce, walnut and clear acrylic. The water jet cutting facilities of London Metropolitan Works were commissioned to cut a tuning fork from 4mm thick float glass.

Due to the nature and requirements of the laser cutting process, materials that would reflect the laser beam back up into its source, such as metals, are not eligible for use. This meant that another method of fabrication was used to create more tuning forks of other materials. The independent craftsman, technician and fabricator Rex Garrod was commissioned to produce tuning forks in stainless steel, mild steel, lead, 60/40 solder, zinc, brass, copper, tufnol, and food grade nylon. Machining the forks from stock material, Garrod set up a jig (as shown in figure 6.3) to insure the correct measurements were achieved when cutting.

Figure 6.3: Rex Garrod in his workshop showing the jig he made for machining tuning forks.

16 tuning forks of different materials were made in order to investigate the acoustic properties of materials (see figure 6.4). Of these, nine employ materials plotted on the Ashby and Johnson MDS map of acoustic properties. These materials are brass, glass, lead, nylon, mild steel, stainless steel, zinc and balsa. All of the tuning forks have differing frequencies and offer a set of material-objects that can be encountered in order to investigate the effect of materiality on acoustics.

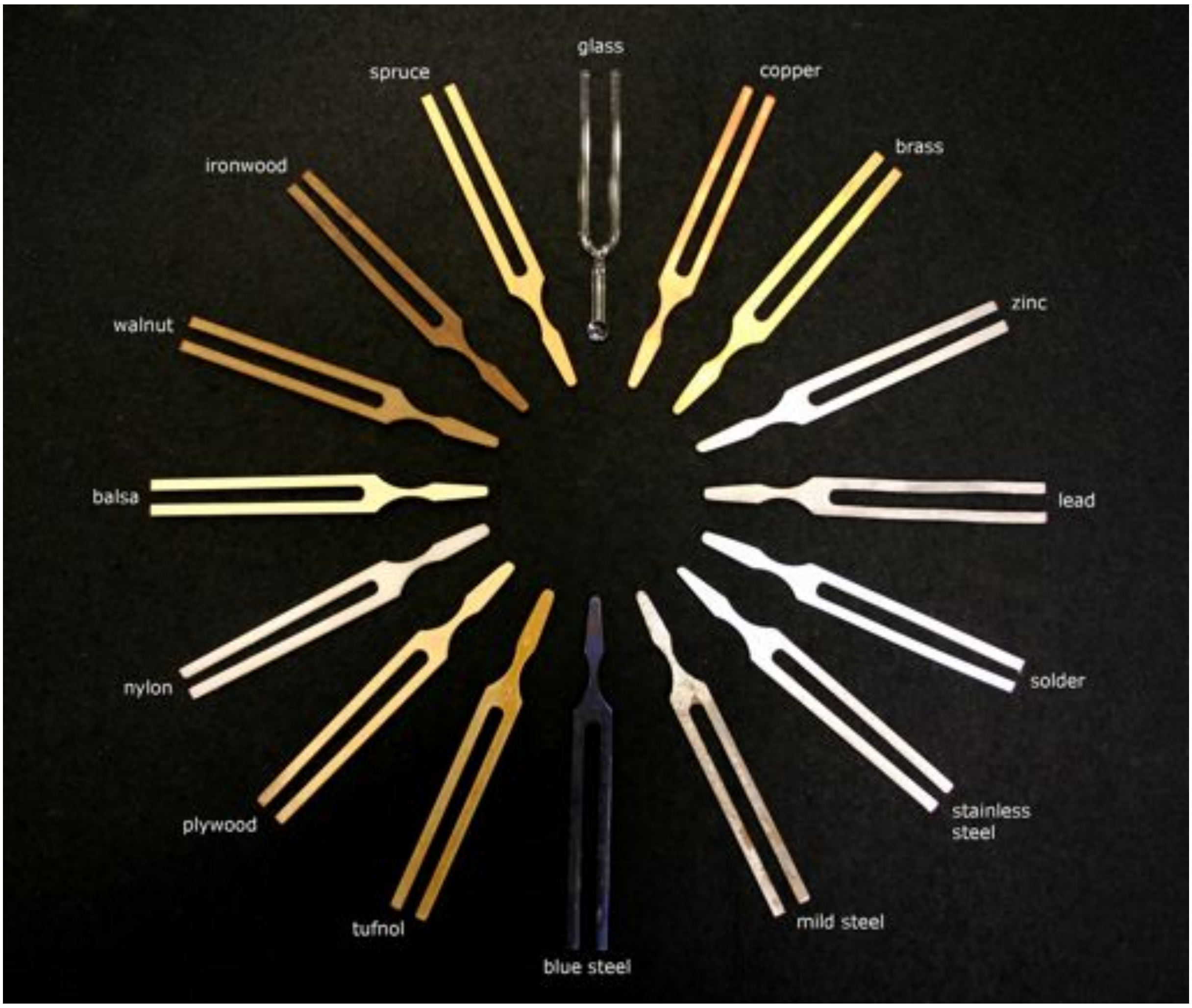

Figure 6.4: 16 tuning forks of different materials made for the Materials Library to demonstrate the acoustic properties of materials

6.2 Encounters

This section outlines the encountering of the set of tuning forks by visitors to the Materials Library. As was the case with the cubes, the materials librarian (the author) hosted each visit and keep notes in accordance with the methods outlined in chapter . If a visitor declare a specific interest in sound (stating they were a musician for example), they were specifically asked to play the tuning forks and attempt to put them in acoustic scale order and their response logged on a specific data sheet. If a visitor did not declare an overt interest in sound, they were still free to encounter the forks, though not directly instructed to place them in acoustic scale order. The concept of the encounter is primarily defined by the haptic exploration of the material-object by a visitor. In the case of each tuning fork, this haptic exploration takes the form of the handling and physical playing of a tuning fork by a visitor and the experiencing of the phenomena that occur.

The tuning forks are laid out in a row, side by side in the following order; blued steel, stainless steel, mild steel fork, lead, solder, zinc, copper, brass, glass, spruce, iron wood, balsa wood, plywood, bass, obeche, walnut, acrylic, and nylon. Initially, the tuning forks are appraised visually by the visitor with the isomorphic nature of the objects recognised and their presence as a set noted. The form of the objects is identified by the visitor as that of a tuning fork and thus recognition of its form and its potential function precedes the haptic exploration.

The playing of a tuning fork is characterised by the firm holding of the fork at the base, the striking of the prongs against a hard surface or pinching to two prongs together and then the free oscillations of the prongs. Once the prongs are oscillating, the vibrations this produces can be both heard and felt by the hand grasping the fork. In order to hear more clearly the sound produced by the fork, visitors often hold the fork up to their ear or, after the instance of striking, placed the base of the fork handle onto a wood surface that then acts as a sounding board, amplifying the sound produced. If a visitor is unsure of how to play a tuning fork, either expressing this in words or demonstrating it by failing to play the forks in a manner that would induce a sound, the materials librarian (thesis author) would demonstrate the two methods and suggest the quite forks be pinched directly next to the ear to insure the sound is heard.

Visitors are free to play as few or as many of the forks as they wish, in any order they like, thought the style of their presentation offers an order of systematic playing if so desired. Visitor were also invited to describe their experience and discern the differences in pitch between forks. The following outlines the experience of a number of the tuning forks by visitors to the Materials Library.

The tuning fork of blued steel is a dark metallic blue in appearance and feels fairly cool to the touch. On playing the blued steel fork, the sound is clearly heard by the visitor when the vibrating fork is lifted to their ear and makes an equally loud sound for all to hear when placed on a sounding board. The note sustains for a fairly long time and is regarded as “bright” and “strong” (09-11-06) with the vibrations produced clearly felt in the hand of the visitor.

The mild steel tuning fork has a dull grey metallic appearance and signs of spotted rusting can be both seen and felt on the surface of the material. The sound produced by the mild steel tuning fork is found by the visitors to be “near identical” (20-03-07) to that of the original blued steel fork, with no perceivable shift in the tone produced.

The stainless steel tuning fork is a light silvery colour and very shiny in appearance with signs of brushing on the surface of material evident. On striking, the vibrations produced can be felt by the hand of the visitor and sustain for the duration of the note. In contrast to the blued and mild steel forks, the frequency produced by the stainless steel tuning fork is greater, producing a note of a slightly higher pitch and less duration.

With a matte dark grey appearance, the lead tuning fork is slightly warmer to the touch than the steel tuning forks. In contrast to all of the steel forks, the lead tuning fork makes no audible sound when played but slow vibrations can be felt in the hand. The prongs of the fork are readily deformed when struck by visitors, no matter how much care is taken to play the fork delicately. If a visitor submerges the tuning fork in liquid nitrogen until it reaches the same temperature as the liquid (–196°C), and then plays it (making sure to wear the appropriate protective gloves at all times), the tuning fork is still prone to slight deformation and no audible frequency is produced.

The zinc tuning fork is light metallic grey in colour and has a slight shine to it. On playing, the zinc tuning fork makes no audible sound and the prongs are observed to deform if struck forcibly by a visitor. Minimal vibrations are felt in the hand of the visitor who plays the fork, but these vibrations are of a vary short duration.

The copper tuning fork has a bright metallic orange appearance, the surface of which tarnishes and oxidises easily when handled and exposed to the air, meaning the material appears darker and duller if not cleaned. When played, the tuning fork made from copper emits a tone of low pitch, quiet volume, and short duration. The vibrations produced can be felt in the hand of the visitor, though the intensity of the sensation is less than that of the blued steel fork. In order to hear the sound produced by the fork, the visitor must hold it close to their ear and take care not to touch the prongs against any surrounding hair for this distorts and dampens the already short lived sound.

The brass tuning fork has a bright yellow metallic appearance, though like the copper fork, this appearance changes over time as the result of handling and exposure to air. If the fork is not cleaned, the surface of the material oxidises to produce a darker and duller protective layer. When played, the brass tuning fork gives a loud bright tone of a pitch higher than copper but lower than the blued steel fork. The note is clearly audible when held some distance from the ear and makes a clear and sustained sound when placed on a sounding board. The duration of the note produced is longer than any other of the forks and “the vibrations continue to be felt” (20-03-07) even after they are no longer detectible audibly.

Clear and transparent in appearance, the glass tuning fork is cool to the touch and on the realisation that it is made from glass, the tuning fork is approached for playing with some hesitation and trepidation. The visitor fears that the force needed to induce the oscillation of the prongs will cause the fork to shatter (16-07-07) (20-03-07) (09-11-06). With this in mind, the visitor tentatively taps the prongs against a hard surface to induce vibrations with what they judge to be the minimum of required force. On holding the tuning fork up to their ear, the visitor can clearly hear a quiet but “bright and high tone” (16-07-07) being produced and feel the vibrations of the fork in their hand. The note sustains for a reasonable period of time and is deemed to be higher in pitch than any other of the forks.

Comparatively warm to the touch, the tuning fork made from spruce is clearly wooden; reddish brown in colour with a compact, straight and parallel grain clearly evident. When played, the spruce tuning fork produces no audible ring, but rather a singular note of no duration is produced when the fork is played in a specific way. Firstly the visitor needs to hold the base of the fork firmly in one hand and bring it close to their ear. Following this the visitor places their thumb and forefinger in opposition at the end of the prongs, pinches the prongs together and then sharply releases the pinch, effectively flicking the prongs and provoking them to vibrate. At this instant a note can be heard and the vibrations produced felt in the hand of the visitor (20-03-07) (16-07-07). When played in this fashion, the sound produced is higher in pitch than the brass fork and is closer in pitch to the blued steel master fork than any of the other forks.

The other tuning forks made from wood also produce audible notes when played using the pinch technique. The range of notes produced is not inconsiderable, with obeche, walnut and bass all producing tones higher than spruce, closer to the blued steel, whilst plywood, balsa and iron wood all produce notes lower than spruce with both balsa and plywood emitting tones lower in pitch than the copper fork.

The nylon tuning fork is off-white in colour and is regarded as ‘plastic’ in appearance by visitors, with a dull matte finish. On touching, the fork is deemed relatively warm and the appreciation of the material as a plastic is enforced. On playing, the nylon tuning fork produces no sound when struck in the conventional manner but when played by the visitor using the pinch technique, produces a very low note of no duration. The pitch of the note produced is considerably lower than that of the copper fork and regarded by the visitors as the lowest of all the tuning forks.

The acrylic tuning fork is transparent in appearance and again perceived as a type of plastic by visitors. On handling it is felt by visitors to be slightly less warm than the nylon fork and a little bit harder. When played by pinching, it is very difficult to hear a clear sound emitted from the fork that can be identified by the visitor as the tone produced by the material. On occasions when a tone is perceived it is regarded as slightly higher than the tone of the acrylic fork but very similar in its dull thudding quality.

6.3 Reflections

This section examines causes of the acoustic phenomena that are produced, with a focus on specific tuning forks. This section also reflects upon the successes and failures of the tuning forks as material-objects with a specific relationship to form, function and performativity, that begin to map the territory of the acoustic properties of materials.

6.3.1 Performance

Performance plays a major part in the encountering of the tuning forks, in relation to the parts played by the visitor, the tuning fork and the material.

> **performance • n. 1 a.** The accomplishment or carrying out of something commanded or undertaken; the doing of an action or operation. **b.** The quality of execution of such an action, operation, or process; the competence or effectiveness of a person or thing in performing an action; spec. the capabilities, productivity, or success of a machine, product, or person when measured against a standard. –DERIVATIVES **performative** adj. & n.

The visitor is clearly engaged in "the doing of an action" when they undertake the playing of a tuning fork. They perform a specific task that requires them to establish through the practice of trial and error, a successful technique to produce a specific outcome. Mechanically, the playing of a tuning fork is a relatively simple task, requiring minimal technique and no musicality. The correct sound is simply the fixed tone produced when the fork is struck and the prongs allowed to oscillate freely. The simplicity of its use, coupled with its relative familiarity to large numbers of people, means that it is a useful demonstration object, requiring no training to produce a sound from it. Minimal trial and error establishes in visitors a standard method of playing that can be applied to all of the tuning forks.

In performing the task of playing the tuning forks, the visitor enables the enactment of the tuning forks as objects. To best understand this concept, imagine tuning forks that were never played by a visitor, never enabled to produce a phenomena but simply existed as a set of material-objects made in a specific form, from specific stuff. In this case, the tuning forks would simple be a three dimensional representation of the sound of materials. It is not until the act of playing occurs that the fourth dimension of time is added and the forks fulfil their functions as tone generators.

The functionality of the tuning fork not only depends upon the specific nature of the form and how it performs when struck, but the performance of material from which it is made. The properties of elastic modulus and density, as shown in section 6.1, are the primary properties that are material dependent and effect the pitch of note produced. These properties are therefore key to the performance of the material when made into a specific form. Coefficient of loss on the other hand, is a type of performance that acts as acoustic dampening but the specific properties that are the cause of the effect are not well understood. Combinations of factors from temperature and mechanics, to structural defects and imperfections can all play a part in the performance of the coefficient of loss.

With regard to the encountering of the tuning forks, all three aspects of performative agency are embraced; that of the *doing* visitor, the *functioning* form and the *behaving* material. These three elements of the encounter effect and depend upon one another, working towards the enactment of the material-object as a representation of acoustic phenomena that can be physically experienced.

6.3.2 Scientific Representation

The frequency equation (see equation 6.1) and the MSD map (see figure 6.1) predict that the property of acoustic pitch, in relation to a given material, is directly related to the density and elastic modulus of the specific material. The following table records the approximate values of density and elastic modulus for the tuning forks where these values are known for the material used. The ratio of elastic modulus (E) to density (ρ) has been calculated (E/ρ) in order to give a numerical guide to the relative pitches of the tuning forks. As the exact value of frequency is not given, the exact musical pitch can not be determined, but a guide to the relative increases and decreases in pitch can be seen by the increase and decrees in the values of E/ρ.

tuning fork	pitch of note	E	ρ	E/ρ
blued steel	predicted highest	210	7.86	26.72
mild steel		210	7.86	26.72
stainless steel		190	8.00	23.75
spruce		9	0.45	20.00
zinc		108	7.14	15.13
brass		113	8.50	13.29
copper		117	8.96	13.06
nylon		3.1	1.15	02.69
lead	predicted lowest	16	11.34	01.41

Table 6.1: The elastic modulus (E) and density (ρ) of some of the tuning forks, along with their stiffness to density ratio (E/ρ), providing an overview of the predicted relative pitches

Table 6.1 provides an order of the tuning forks that relates to the relative pitch of the notes produced, as predicted by the frequency equation, revealing a number of interesting results. For example, despite values of elastic modulus and density well below that of any of the metals, the spruce tuning fork should produce a note at a pitch between that of the blued steel and the brass fork. On playing this is found to be correct, but with the quality of the note produced by the spruce fork, differing from the two metals in its inability to ring. The fact that any wooden fork can produce a note of a pitch that is comparable to any metal is of it self surprising to some visitors.

The materials that occupy the top and bottom positions of table 6.1 are also of interest when regarding the table as a whole as it can then be assumed that they will provide the extremes of experience when played. Created from pure silica (SiO), the glass tuning fork has a density (E) of 2.203 g/cm^3 and an elastic modulus (ρ) of 73.1 GPa, resulting in a stiffness to density ratio of 33.18 E/ρ, the highest of all the tuning forks in table 6.1. This is confirmed when played, the glass tuning fork is heard to produce the note with the highest frequency of all the forks.

Lead, with a density of 11.34 g/cm^3 and an elastic modulus value of 16 GPa has a stiffness to weight ratio of 1.41 and sits at the bottom of table 6.1. From this data the lead tuning fork is predicted to produce the note of lowest pitch. At room temperature lead is a very soft metal, relatively close to its melting point when compared to the other metals. As a result, the prongs of the lead tuning fork deform when struck as the material exceeds its elastic limit. In the act of striking, as most of the energy is absorbed by the material as it deforms, minimal vibrations can be felt in the material as the prongs never have the opportunity to oscillate, allowing the energy given in striking to be transformed into vibrational energy perceived as sound. This is even the case when the material is dramatically cooled in liquid nitrogen to −196°C in an attempt to increase the stiffness.

The order of the tuning forks produced in table 6.1 is supported by the experimental evidence generated in the experiential encountering of each fork through its playing. The predictive data also aligns with the recorded results shown in table 6.2. The recorded frequency of each fork is the average frequency values of five recordings of each tuning fork. MATLAB, the interactive environment for algorithm development, data visualisation, data analysis, and numeric computation (MATLAB, 2008), was used to digitally record and analyse the data. The standard MATLAB function, ‘wavrecord’ was specifically used to interface the acoustic signal and the resonant frequency of each tuning fork was measured by extracting the peak to peak time interval of the wave function. Not all the tuning forks were able to be recorded due to the low aptitude of the sound produced or the fact that in fork was damaged during an instance of encounter.

The results of both the encountered experience and formal measurement of the stainless steel tuning fork do not place this fork in the predicted position when ranking them in order of pitch. If the results were to correspond with the prediction, the frequency value of the stainless steel fork would be less than that of the mild and blued steel forks. As it is however, the stainless steel fork has a frequency value greater than the mild and blued steels, suggesting that the values of E or ρ for the stainless steel fork my be incorrect and the exact composition of the material different to that expected.

tuning fork	E/ρ	Hz
blued steel	26.72	441.4
mild steel	26.72	441.4
stainless steel	23.75	452.2
spruce	20.00	333.8
brass	13.29	312.2
copper	13.06	279.9
nylon	2.69	129.2

Table 6.2: This table lists each of the tuning forks and their corresponding stiffness to density ratio (E/ρ) values, along side their recorded pitch (Hz).

Those forks deemed higher than others when played, do appear above those forks calculated and recorded to be of a lower in pitch. The question of how much higher or lower one fork is from another can be viewed mathematically as shown in the table. Table 6.3 takes four of the tuning forks from table 6.1 and illustrates the numerical difference between the E/ρ ratio of each fork, listing this difference as Δf. The numbers show that the glass fork should be higher in pitch than the blued steel fork, to the same extent that the blued fork is higher than the spruce, and the spruce is higher than the brass. Experientially, the question of the relative increases and decreases in pitch is one of musical scale and less straight forward to determine by ear alone unless one has perfect pitch, musical training or a very discerning ear. With the right equipment however it should be possible to determine whether the musical interval between the notes produced by these four forks is a even as the numerical intervals of the E/ρ suggests.

tuning fork	E/ρ	Δf
glass	33.18	–
blued steel	26.72	6.46
spruce	20.00	6.72
brass	13.29	6.71

Table 6.3: The difference between the E/ρ values of four specific tuning forks, given as Δf.

6.3.3 Stiffness

Steel is an alloy of iron with a small amount of carbon added, between 0.2% and 2% by weight. Varying the ratios of carbon to iron alters the properties of the steel; the greater the percentage of carbon, the strong, harder and less ductile the material. In particular, mild steel is defined by its low carbon content (up to 0.3% of the total weight) that means it is relatively easy to work with a low tensile strength. The density of steel varies slightly depending on its composition but is generally taken as 7.86 g/cm^3 with an elastic modulus (E) of between 210 and 190 gigapascals (GPa) which are measured as kN/mm^2.

As discussed in section 6.2, the blued steel and mild steel tuning forks look very different but when played, no discernible difference can be heard between the notes produced by the two forks. Although the forks look like they are made from different materials, they are of identical shape and produce a note that is experienced as identical. In fact the blued steel fork is made from mild steel that has been subjected to a passivation process that renders the surface of the steel blue in colour and corrosion resistant, thus less likely to rust in the manner that can be observed on the mild steel fork. Thus we see that surface finish had a negligible effect on the frequency produced by the tuning fork.

Another way to produce a corrosion resistant steel is through the addition of an minimum of 11.5% chromium to the steel alloy and thus create stainless steel. The density of stainless steel is approximately 8 g/cm^3 and most commonly has a elastic modulus of around 190 GPa. The addition of chromium has increased the stiffness of the material which impacts upon the tone of the note produced by the stainless steel fork.

With an elastic modulus value of around 200 GPa, steel is a very stiff material. In the case of all three of the steel tuning forks, their density is similar to that of brass but they have an elastic modulus value nearly twice that of brass. This greater stiffness is shown to have a direct result on the pitch of the note produced as all of the steel tuning forks are notably higher in pitch than the brass fork. This experience is supported by both the data in table 6.1 where the relative E/ρ values of the steels are twice as great as that of the brass tuning fork. This result also concurs with the information of the MDS in figure 6.1, where all steel is shown to have a greater acoustic pitch than all brass.

6.3.4 Density

Copper is a relatively ductile elemental metal with a density of 8.96 g/cm^3 and an elastic modulus of between 110 and 128 GPa. When played, the tuning fork made from copper emits a tone of low pitch, by far the lowest in pitch of all the audible metals[1] due to the fact that it has the greatest density of the audible metals.

Zinc is a relatively brittle metal with an elastic modulus of 108 GPa and a density of 7.14 g/cm^3, closest to that of stainless steel. The zinc tuning fork is also most visually like stainless steel with a light silvery grey colour and metallic sheen. Considering these similarities, visitors find it is surprising to find that on encountering, the zinc tuning fork makes no audible sound, though vibrations can be felt in the hand of the person holding the fork as it is struck.

Brass is an alloy of copper and zinc that can be composed from a wide range of ratios of the two materials with the percentage of zinc ranging from 20% to 50%. The specific brass used for the tuning fork is made from 60% copper and 40% zinc, with a density of around 8.5 g/cm^3 and an elastic modulus of between 103–124 GPa. In contrast to both the copper and the zinc tuning forks, the brass tuning fork produces a note of higher pitch, greater brightness and longer duration. For many visitors it is surprising to learn that alloying copper and zinc together does not result in a material that takes on some of the characteristics of copper and some of zinc, creating a mixture of not only atoms but behaviours. Rather, alloying copper and zinc to form brass is the creation of a completely new form of material with distinct and different properties that can be clearly experienced in its acoustic effect when formed as a tuning fork.

Upon appreciation of the bright, loud and sustaining nature of the note produced by the brass tuning fork, visitors to the library begin to draw comparisons with the use of brass for musical instruments. The composition of brass generally used for brass instruments like trumpets comprises 37% zinc, with a density and elastic modulus close to that previously reported. It is prized for its ability to be easily worked and formed by hand, thus enabling the creation of the complex systems of pipes and tubes that characterise many instruments made from brass. Wind instruments however deal with the vibration of columns of air within chambers and pipes of varying sizes and lengths to produces notes of varying frequencies. The material the chamber or pipe is made from does have some effect on the subtle qualities of sound produced but it is not as dramatic an effect as that seen in percussive instruments where it is the matter itself

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[1] the audible metals are the blued, mild and stainless steels, the brass and copper forks whilst the non-audible forks are the lead and zinc forks. The status of being audible or not is defined by whether it can be perceived by the human ear.

that vibrates to produce the sound. The ability of brass to produce a sustaining note (ring) is the primary reason the material is used for percussive instruments like cymbals that are to be struck and left to vibrate, just as the tuning fork is when played. The phenomena of this sustained ring is directly related to brass's low coefficient of loss that means the material does not dampen the vibrations that pass through it.

6.3.5 Coefficient of Loss

Wood is the name given to the specific type of organic matter produced by the xylem of trees. The xylem is the vascular system of the tree tissue that enables the transportation of water and nutrients from the ground up, by a process of evaporation. As a tree grows, a new outer ring of xylem is generated. The eventual build up of xylem rings can be observed when a trunk or branch of a tree is cut and viewed in horizontal cross section. The xylem of a tree also provides the support structure for the tree, enabling the tree to stand and the fresh living growth to exist around it. Xylem is characterised by long fibres, the alignment and texture of which is regarded as the grain of the wood. Woods from deciduous trees like oak or walnut are known as ‘hardwoods’ and have densely packed fibres, whilst woods from coniferous trees like pines are known as ‘softwoods’ and often have less densely packed fibres in their xylem. This state of ‘hardness’ or ‘softness’ does not always directly correlate with the mechanical property of hardness. For example, balsa wood is categorised as a hardwood but is not at all hard and has an extremely low density of 0.17 g/am^3, making it extremely light and softer than nearly all softwoods.

Spruce is a type of wood produced by a coniferous tree of the genus Picea and is thus classified as a softwood. The fibres of the wood are long and its grain is compact, straight and parallel. With a density of 0.45 g/cm^3, spruce is considerably less dense than any of the non-organic tuning forks and has an elastic modulus value of 9 PGa, when measured parallel to the grain. The data in table 6.1 predicts that the pitch of the note produced by the spruce tuning fork will be less than the steel forks but greater than the brass and copper forks. On playing this is found to be the case but it should be noted that an alternative method of playing must be employed by the visitor in order to generate a sound from the spruce fork. The standard method of striking the prongs upon a hard surface does not generate an audible tone from any of the wooden forks, rather the prongs of these forks need to be pinched together and released when the fork is held close to the ear. The reason for this is two fold. Firstly the sound produced is of extremely short duration, dying out long before the fork can be lifted to the ear. Secondly, the striking of the fork against another object generates a sound in and of itself that masks the sound emitted by the tuning fork. Using the pinching method of playing, notes of varying pitches can also be heard from the walnut, plywood, bass, obeche and iron wood tuning forks.

As a material, wood is not associated with the phenomena of ringing that characterises the sustained resonance normally created by a standard metallic tuning fork. Acoustically, wood is more often associated with the amplification of sound as in its use for the body of acoustic instruments like guitars, violins and cellos. This notion of the wood generating amplification is a misnomer, for as shown by the playing of the wooden tuning forks, wood does not lend itself to the production of sounds of loud volume and long duration. The amplification of sound produced by a vibrating string has more to do with the volume of air contained within the body of the instrument than the vibration of the material from which the instrument's body is made[2]. The role of wood is in fact that of a dampener, absorbing some frequencies whilst enabling the propagation of others in the manner of an acoustic filter. Spruce is used to make both violin and guitar bodies as it is believed by musicians to produce instruments that sound more pleasant with warm and rounded tones. This may be due to the straight parallel grains of high grade spruce that provide bands of alternate hard and soft matter that can be provoked to resonate by desirable resonate frequencies likened to the human voice, with high overtones dampened. Another reason for the popularity of spruce is its superior strength to weight ratio. Having to hold an instrument like a violin up to the neck means that its ability to be both strong and light is paramount. To this end, some violins are even made from balsa wood.

Both woods and synthetic polymers are carbon-based materials with more in common chemically than woods and metals or polymers and metals, though polymer-based instruments (instruments commonly regarded as made from plastic) are far less prevalent than wooden ones. Many polymers have good stiffness to weight ratio and would presumably make cheap and light weight instrument bodies. Whilst cultural conventions, biases and material connotations play their part in producing prejudices against the use of polymers in instruments, the rejection of the use of such materials may have something to do with the subtle qualities of sounds that are emitted by these materials.

Nylon is the generic name for a family of thermoplastic synthetic polymers otherwise known as polyamides that can be modified chemically to effect a range of properties. The nylon tuning fork, with a density of 1.15 g/cm^3 and an elastic modulus value of 3.1 GPa, produces the lowest note of least duration of all the audible forks. The tuning fork made from clear acrylic, another synthetic polymer with a density of 1.19g/cm^3 and an elastic modulus of between 2.64 and 3 GPa, produces an even lower frequency note, hardly audible at all. Both polymer forks need to

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[2] It is important to not that this effect is to do with the amplitude of sound rather than tonal qualities.

be played using the pinch technique, in the same way as the wooden forks do, but unlike the wooden forks, the notes produced are of an extremely low pitch. In other words, they do not have a resonant frequency within the common musical range produced by violins and thus do not literally sing (resonate) when hit with a sound wave of the same frequency, thus enhancing the richness of the acoustic experience.

6.3.6 The Set

Within the context of the Materials Library, the tuning forks are presented together as a set, enabling the efficient reading of them as material-objects that display a specific relationship to one another, bound together by virtue of their isomorphic form and common function as tone generators. They are in effect a swatch of material-objects that invite interrogation and, as a result of having a clearly identifiable form and function, are able to be encountered by a wide variety of visitors without the need for specialist skills or material knowledge.

Various successes and failures of specific tuning forks can be observed when the generation of a tone is regarded as the primary function of this specific object. For an encounter where materiality is to be explored, the failure of some forks as a tone generators is to be embraced as it is the direct consequence of the material from which it is made. The existence and failure of these forks within the set provides an opportunity for the relative comparison of tuning forks and enables the visitor to acquire a broad perspective on the territory of material-dependent acoustic effects. As has been shown with the acrylic and lead tuning forks, some materials make tuning forks that produce no audible sound, negating the object's function and embracing failure as an illustrator of materiality and thus further representing materiality's effect upon function.

It is clear to all visitors which tuning forks are made from metals, woods and plastics for example, though exact identification of materials within these categories is less common. Previous experience of materials affects the assumptions, predictions and suppositions visitors make when assessing the possible sounds they will hear on playing a particular tuning fork. The level of previous experience was often relatively strait forward to gauge as many visitors would declare an interest in a particular material or express and base of knowledge that related to their professional background. Prior knowledge of the behaviour of glass for example, leads many visitors to shy away from the playing of the glass fork. They understand that it should make a high 'ping' sound when played, in the same way as a wine glass would when tapped, but they fear the tuning fork will shatter under the force of their playing. In this act of hesitation the visitor displays their material knowledge and makes predictions accordingly that take into account the experience of playing a tuning fork. They realise that the force they used to play the blued steel fork was considerable and unrestrained, two dynamics they will have to monitor when playing the glass fork.

The ability of the visitor to differentiate between the pitch of notes produced by the tuning forks can vary, depending on the hearing and musicality of the visitor. For example, all of the visitors that declared them selves as musicians (see Appendix F) were able to arrange the forks in the correct acoustic frequency order whilst this was not the case for visitors from a non musical background. In all cases however, visitors are able to discern differences between the pitches of notes produced, thus appreciating how the sound of the fork changes dues to the change in material. The quality of sound is also appreciated by the visitor who experiences the difference between materials that ring and sustain a note, versus those that thud with staccato resonance. Overall, the visitor is able to acquire a relative appreciation of the materials in relation to differences and similarities in their performance, rather than the specific reasons for that performance based upon detailed knowledge of the effects of elastic modulus and density.

Within the act of encounter, the set of tuning forks becomes a physical manifestation of both the frequency equation (shown in equation 6.1 and explored in table 6.1) and the MDS map of acoustic properties (given in figure 6.1). The tuning forks, the equation and the MDS map are in point of fact, three versions of the same thing; three ways of representing the relationship between materials and acoustic properties. The effects of density and elastic modulus are not explained by the tuning forks themselves, this is part of the role of the librarian in discussing the encounter with the visitor, rather, the effects of density and elastic modulus are experienced in the act of playing the tuning forks. As a result of the existence of the set of tuning forks, density and elastic modulus are performed by the tuning forks and enabled as a physical experience of acoustic properties.

6.3.7 Concluding Remarks

In considering the material-object continuum, a tuning fork made from a particular material is more *object* than a cube made from the same material, due to its specific relationship to function. The fact that this function is shown to be material dependent, is the key discovery made by the visitor who plays the tuning forks. It is clearly important to have a range of forks of varying material in order for similarities and differences between the acoustic properties of different materials to be explored, but in order to best focus attention on the effects of density and elastic the presentation of a more limited range of forks may have provide a better way into the science for the visitor.

Changes in material did enable the resultant differences in the performance of the forks to be judged in relation to material density and elastic modulus. Any shift in the frequency of sound produced by each fork was a direct result of the material from which it was made and as a result, the isomorphic set of tuning forks went some way to practically demonstrating and conceptually representing the science of their materials.

Chapter 7

Bells

This chapter introduces the bell as a highly resonant material-object with overt acoustic characteristics that, like the tuning forks, result from the specificity of its form and its material properties. A small set of isomorphic bells are devised and made in order to demonstrate further the sound of materials and convey the effect of materials science through the highly recognisable and functional form of the bell. The bells, as material-objects, are considered in relation to the material-object continuum and nexus of material-objects thus far created in this thesis.

Whilst the tuning forks embodied the functional performativity of materials in relation to density and elastic modulus, their status as a cultural artefact is low, with a few visitors failing to recognise the object of the tuning fork at all. Other, whilst understanding the proposed functionality of the form, required prompting in order to play them correctly and thus hear the sounds produced. In order to find a form that was singular in its material and yet still relevant to the story of materials and their effect on acoustic the form of the bell was selected. Thus the bells were devised and created in response to the cubes and tuning forks as part of a reflexive and progressive methodology of material-objects creation, where "experiments are preformed to bring about outcomes which are subjected to further analysis" (MacIsaac, 1996, p4), outlined previously in section 4.1.2 and illustrated in figure 4.2.

Bells are strong cultural objects that connote meaning to the communities that erect them and bring sonic accompaniment to civic life. The peeling, ringing and tolling of bells offer a range of acoustic and social resonances that can signal anything from the passing of time to celebrations of love after a marriage and warnings of danger in war or fire. From the deep authoritative tolling of Big Ben to the polite but firm tinkle of a passing cyclist, the sounds bells are called upon to produced can vary enormously. The design and specific dimensions of each bell, as well as the material from which the bell is made, will drastically effect the sound each bell produces and thus the meaning it is given (Fletcher and Rossing, 1998, p675).

Bells come in many shapes and sizes and are usually made from cast metal alloys such as bronze or brass, though small bells made of glass and ceramic can be found. The majority of large bells are made from a hard form of bronze that is often termed ‘bell metal’ and consists of around 22–23% tin and 77–78% copper, though variations exists with additional alloying elements like silver giving distinctive resonant qualities to a bell (Fletcher and Rossing, 1998, p731-732). Due to the high levels of tin in such bronze, bell metal has a lower density than that of standard bronze which in turn affects the sound it produces. In all cases, it is important for the material of a bell to be hard in order to withstand the repeated striking inflicted upon the bell in its playing. The toughness of bronze means it is able to do this and survive for thousands of years.

As a form, bells are commonly characterised by their upturned cup shape with an internal clapper suspended from the base of the cup that strikes the bell wall when swung. Figure 7.1 is a graphical representation of a hand bell that shows the constituent parts of a typical rotationally symmetric bell. Variations in the form of bells effect the resonance of the object and thus its sonorous qualities. As a rule, the larger the bell, the deeper the note produced and the thicker the wall of the bell, the louder the sound produced.

The complex harmonics and overtones produced by the striking of any bell demand the skilful casting and tuning of the bell in order to produce sounds of specific pitch and tone (Fletcher and Rossing, 1998, p681). Be they cast and tuned by hand or machine, every bell receives individual attention during its manufacture, with material removed from the inside of the bell through machining to achieve the specific required pitch (Fletcher and Rossing, 1998, p696).

7.1 The Making

Within the Materials Library collection there are two bells of highly similar dimensions, one made from brass and the other from bronze. The brass bell is a traditional school yard hand bell used to signal the end of “play time” and the bronze bell is a Second World War air raid precautions (ARP) warden’s hand bell that was used to signal the “all clear” after air raids. Both of these bells can be seen to the left in figure 7.2. The similarity in form of these two bells afforded the opportunity to develop a set of bells that followed the isomorphic methodology of material-object creation, keeping form constant whilst varying material. The creation of a set

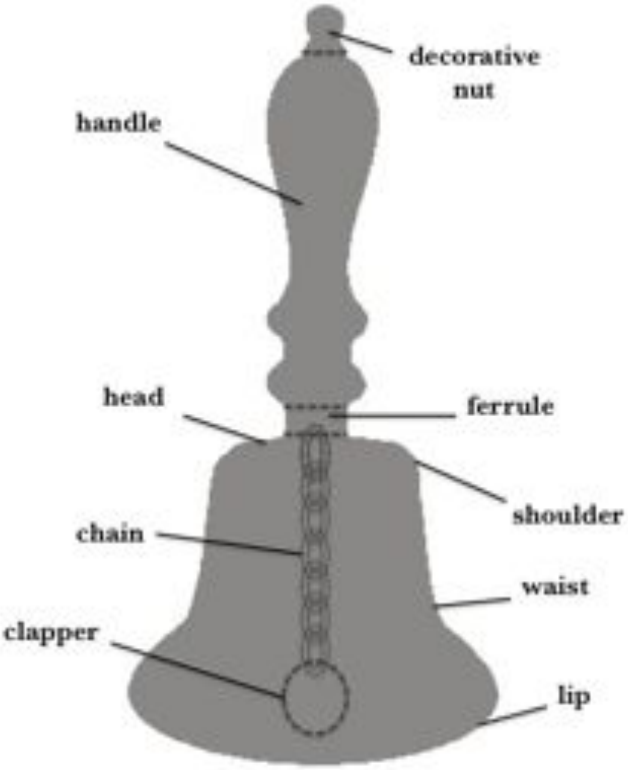

Figure 7.1: A graphical representation of a handbell with its constituent parts and physical features labelled. The form and proportions of this bell were based upon those of the brass school yard bell that forms part of the Materials Library collection.

of bells would bring the investigation of the acoustic properties of materials, initiated by the tuning forks in chapter 6, to bear on a less abstract form, of greater cultural resonance. The ease with which a bell can be both recognised and played brings the material-object investigation of this thesis further towards the object end of the material-object continuum. To accompany the brass and bronze bells, three extra bells were made from glass, lead and mercury. The glass and lead bells can be seen in figure 7.2, whilst the mercury bell is shown in figure 7.3.

Glass

The glass bell (second from the right in figure 7.2) was commissioned from Chemglassware Mfrs Ltd and made by Raymond Tribe, Chemglassware's Technical Director and Senior Glassblower. The original brass school bell was provided for Tribe to use as a master form and to copy as near as exactly in glass. Specific attention was paid the the thickness of the bell wall, the varying circumferences of the bell and the curvature of the waist and shoulder of the bell.

The bell was made from Borosilicate glass tubing that had been manufactured in Germany by Schott. Borosilicate glass is used to make laboratory glassware such as test tubes and conical

Figure 7.2: From left to right: the bronze ARP warden bell, the brass school yard bell, the glass bell and the lead bell.

flasks, due to its superior strength, low refractive index and resistant to thermal shock. In comparison with other glasses, Borosilicate has a relatively low density of 2.23 g/cm^3. The strength of the material was the reason that it was selected for use in the glass bell, though it was noted that its density would have an effect on the sound it produced that would be different from other types of glass.

To make the bell, a five foot length of the Borosilicate tubing was placed on a lathe and heated with a gas/oxygen blow torch[1]. The used of such a heat source is referred to as 'lampworking' and enables extremely high and specific temperatures to be achieved in a controlled manner. The end of the glass tube was sealed and a blowpipe attached for working the glass. The tubing was first drawn down and rounded before the bell shape was blown. Then the domed end was sealed off and a peg formed at the other end. Once cool, the bell was cut off and ground flat. Specific areas of the bell where then flame polished and sand blasted to create the desired surface finish. The glass clapper, chain, ferrule and decorative nut were formed and shaped by hand from Borosilicate rod and finished by flame polishing. Although of no acoustic importance, the addition of the the decorative nut was important to increase the isometric nature of the bell, making it as much like the brass one as possible. All the glass items were made at 800°C - 1000°C, annealed at 560°C and left to cool over night. Finally the chain and clapper were bonded in place using epoxy resin.

The handle was turned from oak on a wood lathe by the author and two holes where drilled in either end. A large hole at the base was made to take the pin of the bell and a smaller one at the top was fashioned for the decorative nut to fit into. Both the bell and the nut were fixed

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[1] The details of the processes employed were provided by Chemglassware's Technical Director, Raymond Tribe during an interview with the author of this thesis on collection of the glass bell.

into the handle using epoxy resin, thus completing the bell.

Lead

Compared with the majority of metals, lead has a low melting point of just 327.5°C making it comparatively soft at room temperature. With a density of 11.3g/cm^3 it is considered a heavy metal and has been used as ballast and weights as a result. It is also a traditional material for making organ pipes, with the addition of small amounts of tin to effect the tonal qualities of the pipes.

The lead bell (far right in figure 7.2) was made by master craftsman, mechanic and maker, Rex Garrod. Due to the highly malleable nature of lead, Garrod did not attempt to make an exact replica of the brass school bell but rather use it as a guide and create a form as near to that of the brass bell. The concern was that the lead would deform under its own weight and that giving a flat top to the bell would accentuate this problem and could see the handle sink into the body of the bell. To prevent this, Garrod designed a bell shape that had a slightly more domed top to it. The difference in the profile of the lead bell can be observed in figure 7.2.

In order to make the bell, the desired shape was first turned out of wood on a lathe. This wooden former was then set into sieved builders sand to make a mould. Molten lead was then cast into the sand and left to cool. The lead bell form that emerged from the sand was then brought to size by turning and finishing it on a lathe. A lead clapper was also cast, though it was not suspended inside the bell on a lead chain. In order to insure the free swinging of the clapper, the mass was suspended inside the bell on a leather fob that was fixed in place by a long thread blot. A lead chain was deemed to prone to deformation under the mechanical strains of ringing to and fro. A handle was turned from walnut, sanded then varnished. The use of a different wood from the glass bell was due to the availability of materials Garrod had to hand. This was not deemed a problem as the materials of the handle has no effect on the acoustic performance of the bell. Finally, a brass ferrule and decorative nut were machined to fit and the bell then bolted together.

Mercury

Mercury has an even lower melting point than lead, of –38.8°C and is unique amongst the metals for it is liquid at room temperature. In order to maintain a solid form, anything made from mercury would need to be kept at a temperature below that of the mercury's melting point.

The mercury bell, as seen in figure 7.3, was made by chemist Dr Andrea Sella in the Department of Chemistry, University College London. The wooden former used in the making of the lead bell was once again deployed in the making of a mould. A two part silicon rubber mould material was mixed together and poured over the wooden former inside a container. Once set, the mould was cut in half and the former removed. The two halves of the mould was then brought back together with a single entry hole made in the top into which the mercury would be poured. The mould was then placed into an insulated bucket containing liquid nitrogen at a temperature of –196°C and left to cool to the same temperature as the nitrogen. Once the mould had frozen, room temperature mercury was pored in bit by bit, building the bell in layers of around 3mm, letting the mercury cool between each pour. A steel wire, visible in figure 7.3, was set into the top of the bell towards the end of the process to serve as a way of attaching a handle to the bell. Once the mercury had set the mould was separated and the mercury bell removed. The author had turned a handle from oak and drilled a hole down length of the shaft. The steel wire was then threaded through the length of the handle and secured at the top by winding it round a nut.

Figure 7.3: The mercury bell made by Dr Andrea Sella of the UCL Chemistry Department. It is required that this bell is stored in a deep freezer at –80°C in order to maintain its solid form. Due to the extremely cold temperature of the material, ice crystals form on the surface of the bell each time it comes into contact with room temperature air, as can be seen in this photograph.

7.2 Encounter

This section outlines the encountering of the bells by visitors to the Materials Library. The concept of the encounter is primarily defined by the haptic exploration of the material-object by a visitor. In the case of each bell, this haptic exploration takes the form of the handling and physical playing of the bells by a visitor and the experiencing of the phenomena that occur.

The bronze, brass, glass and lead bells are presented in the centre of the library space, side by side upon a table covered with a white table cloth in the order shown in figure 7.2. Due to the unstable nature of the mercury bell (it would not survive in solid form for very long at room temperature), this bell was not present in the majority of encounters and resides in a laboratory deep freeze.

Upon entering the space, visitors instantly recognise the form of the bells and in doing so understand their potential as objects that will generate sound. This recognition is often vocalised with enquiring or appreciative comments made towards the bells, or demonstrated by the immediate playing of one of the bells. In the majority of cases visitors initially reach for the brass or bronze bells first. This may be due to the fact that these bells are at the start of the row or that they are recognise as the more normal bells.

Bronze

The bronze ARP warden bell weighs 921.7g and produces a clear resonant sound at a pitch of 1034 Hz, very close to a 6th octave C (C_6) which has a pitch of 1046 Hz. It does not take much force to produce a sound from this bell and it makes an extremely loud and strong sound, even when struck with minimal force. Some visitors are able to identify the material but nearly all of those who encounter this bell are more interested in the history of the object. It is clear to visitors that it is an original object/artefact rather than something made by Materials Library for the illustration of material behaviour and properties. The material of both the bell and the handle clearly appear worn and denote a degree of material age not apparent with the other bells. Some visitors notice the letters ARP that are cast on the surface of the bell rim and either ask what the letters stand for or reveal they know what it stands for and say something along the lines of “so this was used by ARP wardens”, inviting discussion on the history and usage of the object rather than the specifics of the sound it makes.

Brass

The brass school yard bell is heavier than the bronze bell, weighing 1066.4g and produces a sound of a higher pitch at 1497Hz, close to $F\sharp_6$ at 1479.98 Hz. The quality of the sound produced is extremely bright and shrill with an attacking timbre. Few visitors comment on the material used and perceive the bell to be nothing out of the ordinary, in line with the expectations on what a bell should look and sound like.

Glass

The glass bell is the lightest bell with a mass of 293.9g and when struck, produces a sound of 2056 Hz, close to a C_7 at 2093 Hz. The vast majority of visitors approach the playing of the glass bell with some trepidation, revealing this by the careful and tentative way in which they handle and play the bell. Their reservations stem from the fact that they have understood the material from which the bell was made to be glass and bring prior knowledge of this material and its behaviours to bear on the encounter. Glass is a material that is perceived to break easily when struck and thus one assumed unsuitable for making bells out of. Proceeding with caution, the visitor gently rings the bell. The toughness of the Borosilicate glass means that this bell can be played with a surprising degree of force and some visitors begin to play the bell with more force in an attempt to get a sound of greater volume out of it. Although a note is produced, there is very little ring; no sustained note or prolonged resonance of the material is heard. This prompts visitors to attempt to play the bell harder but this produces no distinguishable change in either the pitch or duration of the note, but simply increases the amplitude. Visitors are surprised that the glass bell does not ring (06-08-09, see figure G.14), for although the toughness was thought to be inadequate, the acoustic properties were considered sufficient –a preconception built upon the prior cultural experience of pinging the similar shape of the wine glass and hearing it ring freely. The absence of a durational ring from the glass bell was due to the thickness of glass in the wall of the bell. Because the dimensions had been copied exactly from the brass bell, the walls of the bell were made thicker than one would engineer if attempting to make a glass bell that produced a sustaining note.[2] The role of the materials librarian in the encounter would often be to explain this to visitors and emphasise that not only do different materials produce different sounds but that different amounts (volume and form) of differing materials would be needed to produce similar acoustic effects.

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[2] Raymond Tribe of Chemglassware commented that he could make a glass bell that 'rang' but it would need to have thinner walls.

Lead

The lead bell has the greatest mass of all the bells, measuring off the scale of the equipment available to weigh it, and as a result requires a concerted effort to lift and play. When rung, a note of 775.2 Hz is produced and is close to a G_5 that has a frequency of 783.99 Hz. The sound has an extremely dull, un-metallic and almost wood-like quality to it, with the sound being more akin to a knocking than a ringing. This dull non-ringing sound instantly signals to visitors that this is again a material not normally used in bells. The mass of the bell and appearance of the material suggest for many visitors that the material used is lead. Once this bell has been played visitors tend to return to the other bells and contrast the sounds they produce and begin to ask questions about the materials that tease out similarities and differences in the properties, behaviours and resultant acoustic characteristics. In particular, once a visitor has played the lead bell they are intrigued to know more about why such an object, made from metal, does not ring in a way that the visitor has experienced and expected a metal to ring. The role of the librarian is paramount at this point in order to get to the scientific detail and discuss the phenomena at play.

In some instances of encounter a dewar of liquid nitrogen was available. In this case, visitors were be invited to submerge the bell into the liquid nitrogen until the liquid was no longer boiling off and the bell had reached the same temperature as the liquid, around –196°C. At this point the bell was removed and played, revealing an increase in pitch and a slight increase in the duration of the sound emitted as a result of the stiffening effect of reducing the temperature of the lead.

Mercury

The mercury bell is surprisingly heavy with a mass just below that of the lead bell. When struck it makes a knocking sound similar to that of the frozen lead but at not such a high pitch. The impossibility of the mercury bell having any function in the outside world (the non controlled world outside of the laboratory) makes it an object for the imagination; an exhibit of improbable performance and material impossibilities that brings the role materials play in the functioning of objects to the fore. The value of the mercury bell as a material-object lies in its ability to suggest and represent implausible nodes in the nexus of material-object at which material-objects could only exist under exceptional circumstances, if at all. Especially when the bell is not present, its value in the set of bells lies predominantly in is role as a symbol (or sign (Barthes, 1972)), in the narrative of the set. It serves to represent the ultimate provocation that material can afford to and object, that of the total annihilation of its function. The story of the mercury bell (its creation, and existence in controlled isolation) enables the bell to induce supposing, imagining and conceptualising about the implications material selection has upon material-object functionality, let alone existence.

Instances where liquid nitrogen was available would often facilitate the presence of the mercury bell. It would be transported in a container cooled by liquid nitrogen, from the laboratory freezer in which it lives, to the Materials Library and stored in this container until the time came for it to be played. It would only be able to 'survive' in this state for up to half an hour and then be returned to the freezer. The bell would only be able to 'survive' away from the container cooled by the liquid nitrogen for a matter on minutes. These time limitations produce a dramatic backdrop to any encounter with the mercury bell, with visitors delighting in the possibility that it could melt. One visitor exclaimed "imagine it thawing out and forming a metal puddle, I better not play it for too long" (29-05-08), as they swung it, taped it and scraped at the ice crystals on it's surface.[3]

7.3 Reflections

7.3.1 Objectness

As an object, the bell proved to be extremely recognisable and its function immediately understood by visitors. Evidence for this lies in the fact that all visitors were able to play the object without tuition or instruction, demonstrating their comprehension of the object through physical enactment, as well as the verbal acknowledgement of form recognition. This proved to be a great benefit to the encountering of the bells as a set of material-objects, for there was no misinterpretation or misunderstanding with regard to what one was expected to do with the object and how the object was expect to perform. The connection between the object of the bell and the creation of sonorous percussive sound is so strong that there could be little doubt as to the senso-aesthetic effect presented for examination. The visitor was free and able to explore the phenomena of the sounds the bells produced without any instruction, prompting or intervention.

The simplicity of the bell as an acoustic instrument means it can be played with ease and that the sound produced by any bell is fixed by its design and construction, rather than the skill or technique of the player. In effect, there was nothing the visitor could do to incorrectly play

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[3] On Sunday 29th November 2009, a sustained power failure occurred in central London, effecting the freezer within which the mercury bell was stored, causing the mercury bell to melt. On the following Monday, after the resumption of the power, the mercury bell was discovered in the form of a solid puddle of mercury in the bottom of the box in which it was kept. The addition of this story to the narrative history of the mercury bell has served to underline the bell's mythical status and a sign of object supposing and material performance.

the bell and achieve a ‘wrong’ sound out of the instrument. The differences between sounds produced by each of the bells was clearly audible and thus the effect of the material on the sound of the bell could be heard with ease.

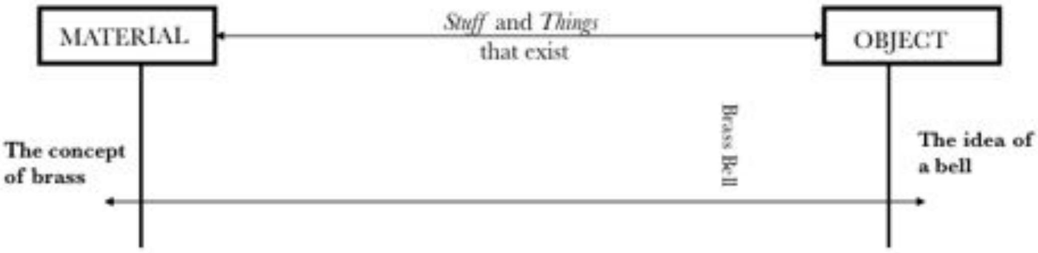

Figure 7.4: The suggested position of the brass bell on the material-object continuum. Placed by the author to give a relative possible location for the material-object, rather than a definitive fixed home. The important factor is that is is more towards the object end of the continuum.

The proposed position of a bell on the material-object continuum (as illustrated in figure 7.4) is further towards the object end than the material end, particularly in the cases of the brass and bronze bells that existed in the world as ready-made objects. Their cultural standing and ever present objectness somewhat overshadowed their materialness. If one simply presents the brass or the bronze bell, they would exist as interesting objects but the the specific relationship between their material and acoustic properties would be difficult to highlight. The high level of objectness in this case draws the bell into the realm of the cultural artefact and runs the risk of negating its materiality.

7.3.2 The Set

Figure 7.5: The suggested positions for the set of bells on the material-object continuum. As the material changes and the function of the object as a bell decreases, so the material status of the bell increases. Again, the locations are not meant to be fixed and definitive, but rather illustrative of a relative dynamic between the bells and the notion of ‘material’ and ‘object’.

The creation of a set of bells that peppered a broader area of the material-object continuum, as represented in figure 7.5, was a way of highlighting the effect of materiality on the performance of a bell and drawing the object more toward the material end of the continuum. The isomorphic methodology, of presenting the same form in a range of different materials, was utilised but the number of materials selected for use was dramatically reduced from the numbers used in chapters 5 and 6. Figure 7.6 illustrates this reduction in the number of materials used in the three sets of material-objects explored in this thesis.

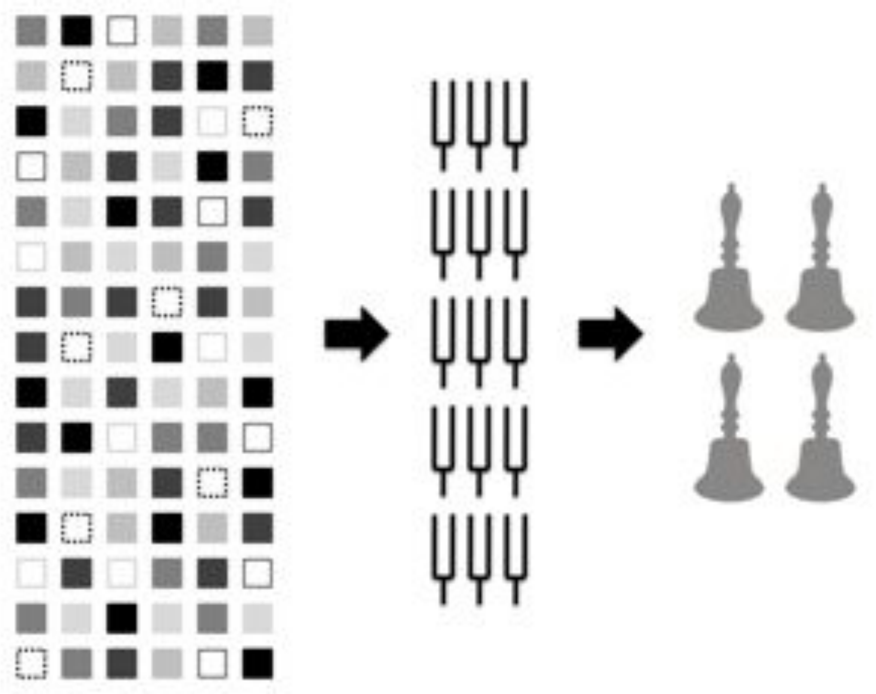

Figure 7.6: The progression from cubes to tuning forks to bells, where the abstract nature of the object decreases along with the number of materials presented. 90 cubes, 15 tuning forks and 4 bells are shown.

The challenge for the set of bells was to reveal the effect materials have on acoustics by using only this small number of materials. In the majority of encounters this was achieved, as the change in both the pitch and quality of the sound produced by each bell was clearly experienced and appreciated by the visitor. In a few cases, visitors expressed a desire to hear a wooden bell and take the material journey away from functionally, that one step further. At such points the wooden former used to make the lead and mercury bells was provided for comparison and was, in many respects, a wooden bell but it was without a clapper and handle, thus requiring improvisation to play it. A formal isometric bell made from wood should be noted as a possible future work outcome of this thesis, providing an interesting companion to the lead bell, that was considered by many to sound rather wooden.

The reduced number of material-objects presented also enabled visitors to play the entire set in a relatively short period of time and thus experience the range of sounds with in a comparably focused way. The limited range of materials meant that there were fewer combinations and comparisons to be made and that the sound of individual bells was less likely to be forgotten or confused during the period of encounter.

When playing the bells, a few of the more musical visitors discovered that the bronze, brass and glass bells (when played in that order) gave notes of ascending pitch at intervals very similar to the first three notes of the trumpet fanfare in *Also Sprach Zarathustra* by Richard Strauss, the music used by Stanley Kubrick over the opening credits of *2001: A Space Odyssey* (1968). In discovering this, visitors were exploring the more musical nature of the bells in contrast to that of the tuning forks. Although there were more notes produced by the tuning forks, the volume and ease with which these could be heard made for a less compositional mode of playing. The role of the tuning forks as a set of *instruments* was less obvious than in the case of the set of bells. The peel, chime and collective playing of bells is an act more commonly performed and thus, as a set, the bells have a collective potential for musical arrangement and ensemble playing.

7.3.3 Concluding Remarks

The brass and bronze bells were both recognised by visitors as found objects (that could have been encountered outside of the Materials Library) and afforded discussion on their use and cultural resonance ((12-01-08), see figure G.12). The glass, lead and mercury bells were more readily understood as devised pieces that were made to demonstrate the practice and principle of material function. The difference between the sounds produced by the brass and bronze bell was minimal when compared with that produced by the glass and lead bells. The sounds of the lead and the glass bells were considered by the majority of visitors to be surprising and thus invited discussion on the reasons for the specific sounds produced by each bell. “Why doesn’t the lead bell ring?” (20-03-08) and “what is the difference between the lead and the other metal bells that means it sounds like this?” (29-05-08), were two specific questions that invited explanation form the materials librarian. the The encountered acoustic effects also prompted discussion around materials, acoustics and musical instruments in general ((29-06-07), see G.5 for an acknowledgement of this discussion area in field notes). The mercury bell was appreciated less for its acoustics and more for the very fact of its creation and existence, prompting discussion between visitors and the materials librarian on material properties and the changing behaviour of materials in differing environmental conditions. This was underlined by the freezing of the lead bell in liquid nitrogen.

In the case of the glass bell, the material overtly mediated the way in which the visitor interacted and used the object. The comparative caution displayed was a direct result and demonstration of their prior materials knowledge and expectations. The fact that the glass bell was found, upon play, to not be as fragile as expected enabled the visitor to establish a new understanding of the behaviours, applications and potential of this material. The role of the material in dictating and mediating the mode of playing was also seen in the other materials for if the brass and bronze bells had not been as robust and tough as they were, visitors would not have felt at such liberty as to give them a loud ring. The high volume and sustained ringing of these two bells provoked people to push them to their limits and see just how loud a sound they could make. The lead bell also caused visitors to mediate their actions as the extreme mass of the bell meant a concerted effort was required to get the clapper to strike the wall of the bell and achieve any sound at all.

The small number of bells did not overtly deter visitors from investigating them or hinder the perception of difference between each of the bells for they repeatedly commented on the nature of the differences in sounds produced ("this bell is much much louder" (07-12-08), "it seems strange the lead bell doesn't ring" (20-03-08) and "I though the glass would sound higher than this" (26-07-09)). If anything, differences in acoustic effect were more swiftly demonstrated than they were by the tuning forks, due to the overt function of the object and the ease with which this function could be explored/the bell played.

Chapter 8

Spoons

This chapter introduces the form of the spoon and applies the isomorphic method of material-object creation to the production of a set of spoons, identical in size but of different materials. The spoons are then used to investigate the taste of inedible materials through formal tests with human subjects. The electrode potentials of the materials are compared to the average subjective taste ratings of participants gathered using psycho-physical measurement techniques to investigate the senso-aesthetics of taste.

Italian architect Ernesto Nathan Rogers (1909–1969) was a post-war editor of the architectural periodical *Domus.* In a 1946 editorial, Rogers suggested that in carefully examining a spoon one can understand enough about the society that made it to understand how they would design a city (Rogers, 1946). This sentiment places the humble spoon at the centre of humanity's designed world, it reminds us that an examination of the materials and processes used to make a spoon can reveal something of the economic, technological and ethical systems of the society that produce it. What, for example, are the economic structures, technical abilities and social mores of a society that mass produces 'disposable' spoons from polystyrene? For Deyan Sudjic, the director of the Design Museum in London, Rogers' declaration shows "the spoon could be understood as a fragment of genetic code –a code that can grow into any kind of man-made artefact" (Sudjic, 2008, p36). As an object, the spoon is at the heart of life; feeding us from infancy and accompanying us in both the preparation, sharing and eating of food the world over, making it a culturally significant artefact experienced by a truly vast number of people (Petroski, 1992). Despite occurring in many different shapes, sizes and materials, the spoon remains instantly recognisable and continuously useful. Commonly made from metals, woods and plastics, the form can be pressed, cast, or machined (Himsworth, 1953).

For many, the experience of taste is one associated with food as matter that is placed into the mouth in order to be consumed. Tastes are received through our taste buds, which are located on the upper surface of the tongue. There are five basic tastes: bitter, salty, sour, sweet, and umami (Ikeda, 2002). These formal tastes are not the only component of the sensations associated with the mouth and the overall experience of tasting. Other important factors include smell, detected by the olfactory system, texture detected by mechanoreceptors, and temperature, detected by thermoreceptors (Lindemann, 2001). The experience of taste in relation to inedible matter is one less appreciated and understood.

'Metallic' has never been widely accepted as a legitimate taste quality descriptor in the psychophysical literature, even to describe sensations induced by electrogustometry (Bartoshuk, 1978). Recently however there has been growing evidence that iron ions, particularly in the form of aqueous ferrous sulphate (FeSO4) may act as metallic chemosensory stimulus (Lawless et al., 2006). Using a multidimensional scaling approach Lawless and Stevens (2006) showed that ferrous sulphate produces a distinctly different sensation from the traditional basic taste descriptors of sweet, sour, bitter, salty and umami which have been shown to have unique receptors (Chandrashekar et al., 2006).

Yang and Lawless (2005) evaluated the sensory characteristics of 10 divalent metallic salts and showed that among the compounds tested, iron compounds were highest in metallic taste; zinc compounds had higher astringency and a glutamate-like sensation; with magnesium and calcium salts producing a bitter sensation (Yang and Lawless, 2005). More recent work has shown that metallic sensations are evoked both by rinses with metal salts and from electrical tongue stimulation (Lawless et al., 2006). Metallic taste sensations have been shown to be multimodal, iron and copper salts in particular have complex olfactory and gustatory properties including a metallic flavour component that is decreased by nasal occlusion. Such studies use metallic salt solutions in varying concentrations to test the taste of a particular metal ion. Oral contact was shown to be important for enhancing the impact of the metallic perception in the case of iron and copper (Lawless et al., 2006). This result provides evidence that metal salts such as ferrous sulphate generate volatile lipid oxidation products in the mouth that are perceived retronasally as metallic flavours. To a lesser extent, copper salts also evoke metallic taste responses, although they are more complex in their sensory properties including bitter, metallic, sour and salty sensations (Yang and Lawless, 2005) and (Lawless et al., 2006).

The focus in the literature on the taste sensations of iron and copper salts seems partly due to their position as convenient soluble non-toxic mediators of 'metallic' tastes, but also because they are important for human health and occur naturally in the water supplies and in food

(Hurrell, 1999). Tap water, as well as spring water, contains varying concentrations of metal ions which affect the taste of the water (Bruvold and Pangborn, 1966) and affect its acceptance as drinking water (Whelton et al., 2007). Copper in drinking water can be an important source of dietary copper for humans, and several iron salts have been introduced as food additives for the prevention of iron deficiency, although their use is not straight-forward since they are strong tasting and can also lead to premature spoilage (Hurrell, 2002).

Metallic tastes arising from metals that are less soluble than iron and copper have been less studied, in particular metals that might come into contact with the mouth not via food or drink, but through utensils during eating and drinking. These metals tend to have very low solubilities and are hard to obtain in solution form.

The chemical aspects of the taste of *inedible* materials are commonly discussed in terms of their reduction potential, in other words the susceptibility of a particular material to being oxidised in the mouth (Bartoshuk, 1978). These potentials have been measured for most metals, and are believed to confirm broad trends of taste: metals that are highly susceptible to oxidisation such as copper and aluminium have a noticeably metallic taste, whereas gold and silver are almost tasteless (Lawless et al., 2006). However, there has been no systematic investigation of the relation between perceived taste and physical or chemical properties of materials in solid form. In other words, it is little understood how the tastiness of a spoon effects the food that is eaten from it, and how the taste of materials effects the experience and perception of them.

8.1 The Making

The spoon was chosen as the isomorphic form because of its high object status; being extremely recognisable and readily associated with eating and tasting, thus providing a material form that people would be conceptually and physically comfortable with having in their mouths. Teaspoons were identified as the ideal type of spoon for this study as the bowl of the spoon would be small enough to fit into any adult mouth with ease, and rest on the tongue without risk of choking.

In making the spoons a number of practical factors had to be taken into consideration. The sensitivity of mechanoreceptors in the mouth mean that any differences in size and texture, no matter how slight, would be instantly felt by the tongue. If the eye, hand or mouth were to detect such differences, the isomorphic nature of the spoons set would be placed in jeopardy. It was therefore important to use a technique to make the spoons that was both repeatable and exact. There was also the issue of health and safety to be considered. To taste the spoons would, quite naturally, involve the placement of each spoon in the mouth by a number of participants, thus requiring the material to be food safe and the spoon to be sterilised between taste tests. Porous or fibrous materials like woods could swell or splinter, thus proving a risk in terms of hygiene and physical safety. The option of making each spoon single-use was rejected due to material and environmental costs. In order to resolve the issue of producing identical spoons from a range of materials that could be washed between uses with little effect on the material, it was decided that pre-existing teaspoons made from stainless steel would be coated in a number of different materials.

Figure 8.1: From left to right: zinc, copper, gold, silver, tin, stainless steel and chrome.

The process of electro-plating was identified as suitable for coating stainless steel in a variety of pure elemental metals. Eight "Sunnex 18/0" stainless steel teaspoons were purchased from a kitchen supplies shop and plated with the following materials; zinc, copper, gold, silver, tin and chrome with a thickness of 10 microns (0.01mm). Although thin, 10 microns provides a homogenous layer with no possibility of exposure to the stainless steel below it. Two of the spoons were not plated and left as stainless steel to be used as control spoons. One of each of the spoons of differing materials are shown in figure 8.1. Each metal was selected on the basis of its non-toxic status, suitability for contact with human skin and mucus membranes, its ability to be electroplated and the ease with which it could be sterilised. The following outlines the information presented on each material to the Research Ethics Committee of King's College London, who approved each spoon for the use of testing the taste of inanimate materials using human subjects[1].

Zinc: Zinc occurs naturally in many foods, the most significant of which are red meats, shellfish,

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[1] Research Ethics Committee reference number: BDM/08/09-74

cereal products (such as bread and wheat germ) and dairy foods (such as milk and cheese). The Foods Standards Agency recommend a daily intake of zinc between 5.5 to 9.5 mg for men and 4 to 7 mg for women. Zinc dietary supplements are widely available; they are designed to aide in the production of new cells and enzymes, and to help the body to metabolise carbohydrate, fat and protein (FSA, 2009). The FSA recommend consuming supplements containing no more the 25 mg of zinc per day, as an excessive and prolonged consumption of Zinc reduces the amount of copper the body can absorb, which can lead to anaemia and a weakening of bones (FSA, 2009).

Copper: Elemental copper occurs naturally in many foods, especially nuts and shellfish and has traditionally been used for both cooking utensils and pans. The UK Food Standards Agency (FSA) recommends a daily intake of 1.2 mg of copper as it aides in the production of red and white blood cells and triggers the release of iron to form haemoglobin -the substance that carries oxygen around the body (FSA, 2009). The FSA warn that supplementary doses of copper (greater than 1mg) taken in conjunction with a healthy balanced diet could result in an excess intake of copper, causing stomach pain, sickness and diarrhoea. Over a long period of time, prolonged high doses of copper might damage the liver and kidneys.

Gold: Though not naturally present in foodstuffs, gold can be added to food with no ill effect to the consumer, and when added, has the E number 175. It is the most inert of all metals and as a result, large amounts of gold could be ingested with no ill effect.

Silver: This material has been used in cutlery for centuries for both cultural and aesthetic reasons (Himsworth, 1953). It poses no risk to health in the context of tasting the material and is considered an additive when present in food and signified on ingredients lists by the number E174.

Tin: Although not considered needed by the body for healthy function, tin is found in many foodstuffs as the result of being stored in cans. By law, the maximum amount of tin that is allowable in foods as a result of contamination from the can is 200 mg of tin per Kg of food (FSA, 2009). Tin also accrues naturally in fresh foods as a result of the composition of the soil in which the food was grown.

Stainless Steel: Stainless steel is the most commonly used material in the production of modern cutlery (Himsworth, 1953). It routinely comes into contact with the mouth when eating a wide variety of foods. We do not know of any studies reporting ill effects of stainless steel cutlery on health.

Chrome: Commonly found in many foods and in multivitamin food supplements in the form of trivalent chromium, chrome thought to be essential for the normal action of insulin. The current consensus is that consuming 10 mg or less of trivalent chromium a day is unlikely to cause any harm (FSA, 2009). Chrome is also the material added to steel to make it stainless and is thus present in all items of stainless steel cutlery.

8.2 Encounter

Unlike the cubes, tuning forks and bells, encountering the spoons was staged as a formal scientific study into the psycho-physical properties of materials. The spoons, as an isomorphic set of material-objects, were presented for encounter in order to gather data on the human experience of the taste of materials that could be mapped against the reduction potential of the same materials. The following outlines the methods of the experiment that constitute the formal encountering of the spoons.

8.2.1 Participants and their Recruitment

32 participants of mixed ages and both genders were recruited for the study from the Materials Library mailing list[2]. To participate in the study, recruits were required to be between 18 and 65 years of age, and in good general health. Specifically they were informed that if they were pregnant, suffering from a cold or flu, or afflicted by any general medical condition known to compromise their senses of taste and smell[3], then they could not participate in the study. The upper age limit of 65 was set in an attempt to negate the effect of the loss of taste sensitivity during the normal ageing process (Schiffman, 2009). No bias was given for or against anyone as a result of their gender, ethnicity or nationality. Upon agreeing to take part in the study, all participants signed a consent form but were free to withdraw at any point.

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[2] Interested parties can join the Materials Library mailing list free of charge at the following address www.materialslibrary.org.uk/MaterialsLibrary/contact.htm

[3] Specific conditions that would automatically rule out a participant from inclusion from the taste of materials study were; taste-based synaesthesia, any disorders of olfaction (anosmia, hyperosmia, hyposmia, dysosmia) and any disorders of taste (ageusia, dysgeusia).

8.2.2 Method

Eight teaspoons (2x stainless steel, 1x zinc, 1x copper, 1x gold, 1x silver, 1x tin, 1x chrome) were laid out between two clean white kitchen towels. The temperature of each spoon was taken, along with the temperature of the room. Participants were seated in front of the covered spoons and talked through the experimental procedure. Once happy to continue, a video camera was set to record and the participant placed a blindfold around themselves to ensure the differing appearance of the spoons did not effect their responses.

The spoons were then uncovered and the handle of the first spoon placed in the hand of the participant, who then placed the bowl of the spoon into their mouth. After the spoon had been in the participant's mouth for three seconds, the experimental supervisor (the author) would then say an adjective and ask the participant to rate the spoons from 1 to 7 (a system based on the Likert scale) in accordance with the following subjective adjectives: cool, hard, salty, bitter, metallic, strong, sweet and unpleasant. For example, if asked whether the taste of the spoon were sweet, the participant was asked to give a value between 1 and 7, with 1 being not at all sweet and 7 being very sweet. Participants were required to rate the spoons in the light of their previous experience of spoons in the world –a sense of an expected and experienced state of 'spoonness'.

Through the course of the encounter, participants were free to take the spoons in and out of their mouths at will whilst considering and rating the adjectives. A glass of room temperature mineral water and a receptacle for the disposal of waste liquid was available for each participant, so that they could drink (and expectorate if desired) after the tasting of each spoon in order to cleanse and neutralise their palate. Participants were instructed to insure their mouth felt as neutral as possible before signalling their readiness to receive the next spoon.

Each participant tasted the spoons in differing, randomly generated orders, except for the first spoon which was always one of the stainless steel spoons. The randomisation of the order of spoon tasting insured that results would take into account any accumulative effect of such tasting. The two duplicate stainless steel spoons were included to test for the repeatability and consistency of the participants' blind subjective reports. Testing a spoon twice within the same test series enabled cross correlation of results to determine whether the participant reacted to the material the same both times. The order of the adjectives participants were asked to rate the spoons in accordance to, was fixed throughout the study.

Once they finished tasting the spoons, all spoons were washed in hot soapy water and then steam sterilised for ten minutes. Once sterilised, the spoons were removed, dried and left to cool to room temperature (repeatedly measured and found to be 21°C) before being wrapped in fresh kitchen towel ready for the next participant. Whenever the spoons were handled by the experiment supervisors, clean white cotton gloves were worn in order to maintain the sterilised status of the spoons. All sterilisation procedures were explained to participants before the experiment began in order to reassure them as to the safety of the task and care that was being taken.

8.3 Reflections

8.3.1 Data Analysis

The subjective experiential data was analysed using standard statistical techniques. Repeated measures one-way analysis of variance (ANOVA) with Tukeys Multiple Comparison Test was performed using Prism 3.0 (Graphpad Software Inc., La Jolla, California). For testing the order effect, which was considered undesirable (and therefore was sought with greatest power possible), in addition to the Tukey comparisons from the ANOVA, the planned analysis included individual participant's paired T tests comparing the first spoon, which was always stainless steel, to the other stainless steel spoon, which was randomised in the order.

Plots investigating the correlation between the perceptions and the relevant physical or chemical property of the pure metals were obtained using standard physical and chemical data sources (Latimer, 1952), (Atkins and Jones, 2005) and (Vanýsek, 2009). For copper and gold, the electrode potential of two oxidation states were plotted since both could be formed in the mouth.

8.3.2 Results

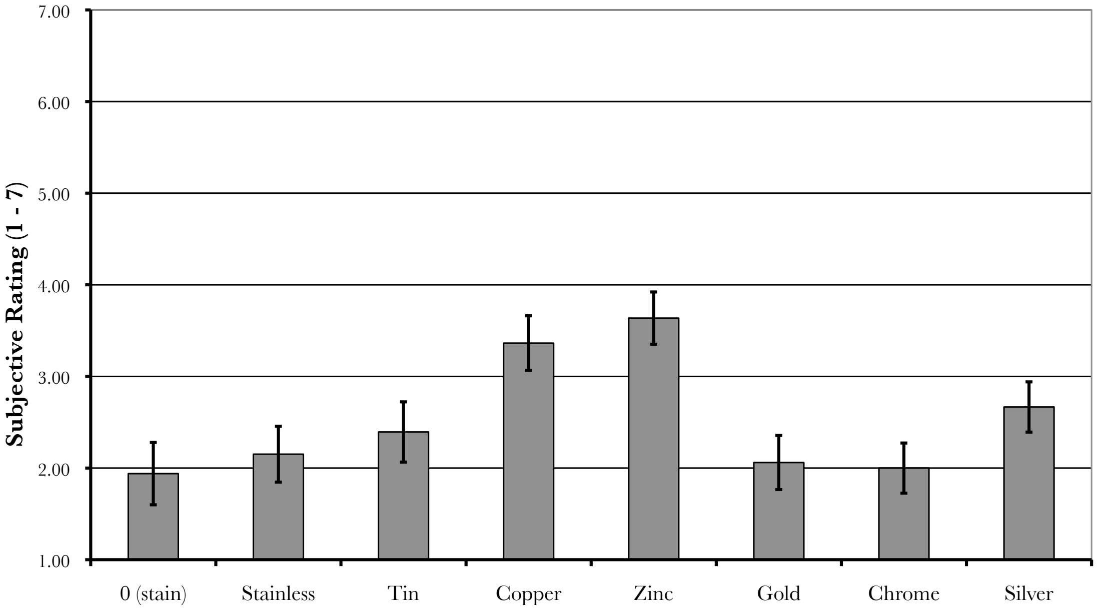
Figures 8.2 to 8.9 contain the bar charts for the average subjective rating response to each spoon with standard deviation error bars. Also shown are plots investigating the correlation between the perceptions and relevant physical or chemical properties of the pure metals obtained from standard physical and chemical data sources (Latimer, 1952), (Atkins and Jones, 2005) and (Vanýsek, 2009). All the adjectives measured by Likert scale (unpleasant, bitter, strong, metallic, sweet, cool, salty) with the exception of hard, varied significantly by metal ($P < 0.001$ for all seven). R2 values demonstrated that the extent to which variability for each adjective was attributable to metal was wide-ranging ($R2 = 0.2720$ for unpleasant ; $R2 = 0.1990$ for bitter ; $R2 = 0.3923$ for strong ; $R2 = 0.2870$ for metallic ; $R2 = 0.0953$ for sweet ; $R2 = 0.1976$ for cool ; $R2 = 0.1045$ for salty). In using the Tukey multiple comparison test to determine which spoons were statistically different, zinc and copper were found to almost always differ from other spoons (although not from each other).

Figure 8.2(top) shows that the strong-tasting metals, copper and zinc, were significantly more bitter than stainless steel, gold, and chrome; however, silver was not significantly different from either zinc or copper, and tin was not significantly different from copper ($P > 0.05$), although it was significantly different from zinc ($P < 0.01$). Figure 8.2(bottom) shows a clear inverse linear correlation between the electrode potentials of metal ions and perceived bitterness of the metals. The one exception is tin which appears to be less bitter than expected from the linear correlation.

Figure 8.3 shows the results for the adjective metallic. Both zinc and copper differed from every other metal ($P < 0.001$) but not from each other ($P > 0.05$); no other pairs of spoons differed in their perceived metallic taste, and these will be referred to as having a metallic taste. There is a weak inverse correlation between the electrode potentials of metal ions and perceived metallic taste of the metals. An identical pattern was observed for the adjective strong (see figure 8.4). For this reason zinc and copper will be referred to as strong-tasting, while the other metals will be referred to as mild-tasting. A near-identical pattern was seen with the adjective unpleasant (see figure 8.5), with the minor exception that the difference between silver and either copper or zinc was only significant to $P < 0.05$; silver was not significantly more unpleasant from the other the other mild-tasting metals. None of the metals differed in saltiness (figure 8.6) or sweetness (figure 8.7).

Figure 8.8(top) shows the average subjective rating of each spoon given in response to the adjective cool. All the spoons were measured and found to be at room temperature (21°C) at the beginning of the experiment. The majority of participants reported finding coolness difficult to judge over the course of the experiment. The fact that the stainless steel reference spoon ("0(stain)" in the plots) was rated as significantly cooler than all other spoons, including the other stainless steel spoon, suggests that coolness was significantly sensitive to an order effect. This was the only sensory descriptor in this study that suffered from an order effect (determined by T tests). Figure 8.8(bottom) shows how the thermal conductivities of the spoons vary widely, and the lack of perceived sensitivity to this materials property is likely to be due to the fact that apart from their surface electro-plating, each spoon was an identical stainless steel spoon, and so it is the bulk thermal properties of the spoon that are being perceived.

Figure 8.9 shows the average subjective rating of each spoon given in response to the adjective hard. The results show little variation across the spoons and were deemed by the vast majority of participants as similarly hard (Repeated Measures ANOVA, $P > 0.50$, $F(7,32) = 0.65$, Tukey's multiple comparison test P > 0.05 for all pairs). This is likely to due to a similar reason as for the coolness insensitivity, namely that the majority of the material bulk of each spoon was stainless steel.



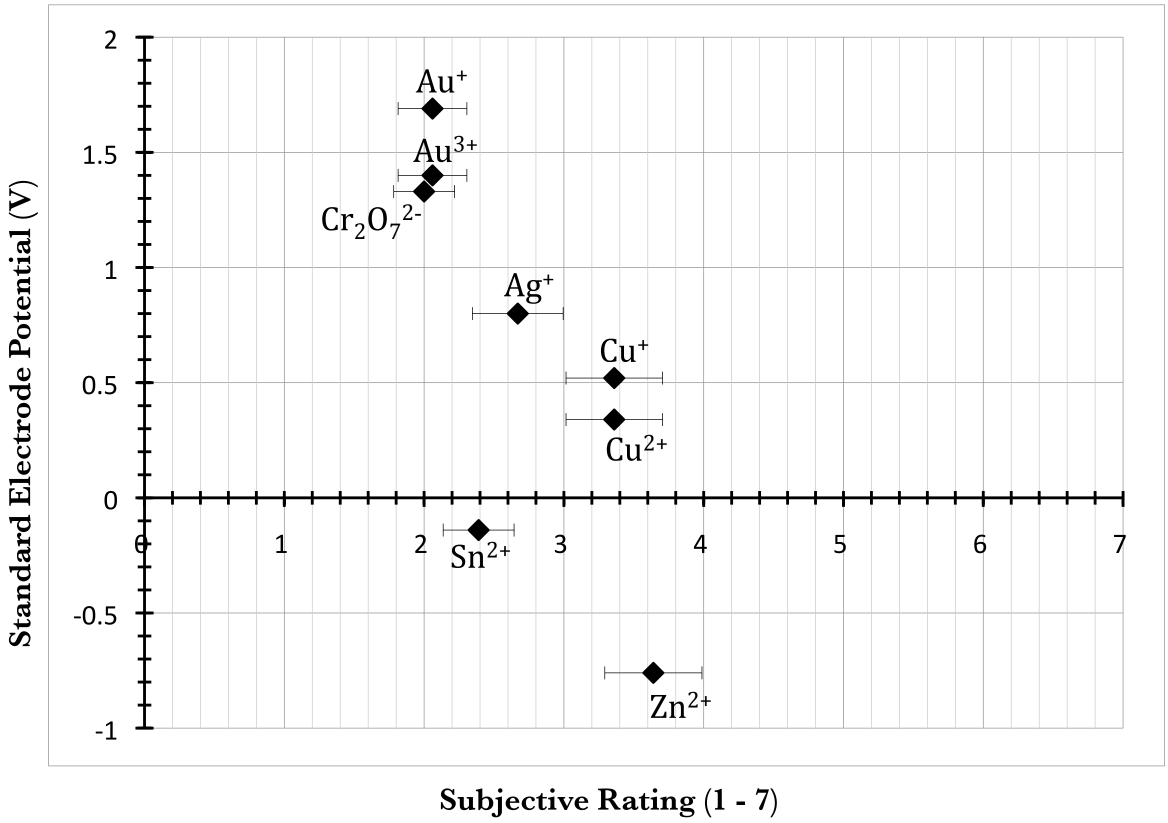


Figure 8.2: (top) The Subjective ratings of each of the eight spoons in response to the adjective *bitter*; (bottom) Perception of bitter plotted as a function of standard electrode potential.

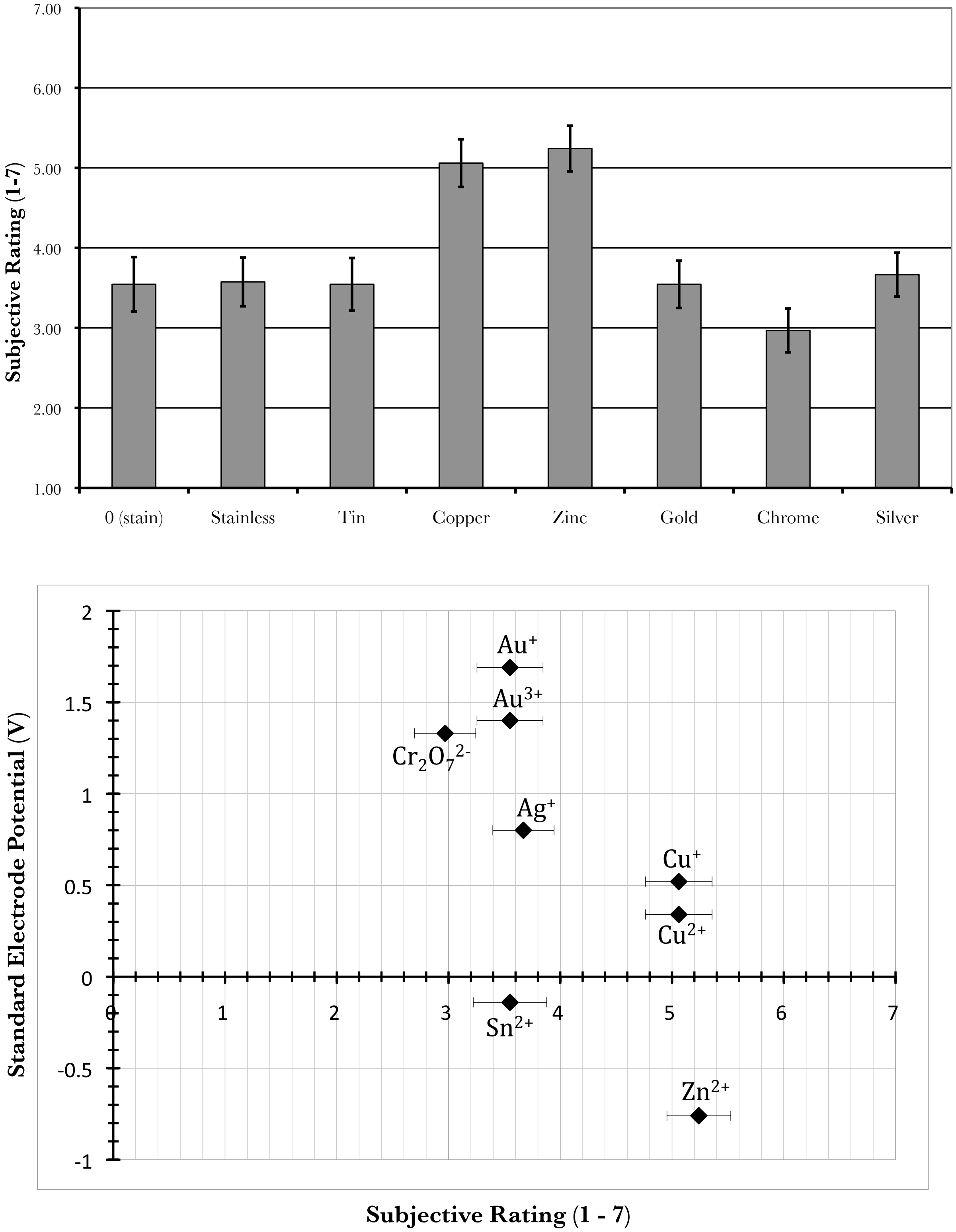


Figure 8.3: (top) The Subjective ratings of each of the eight spoons in response to the adjective *metallic*; (bottom) Perception of metallic plotted as a function of standard electrode potential.

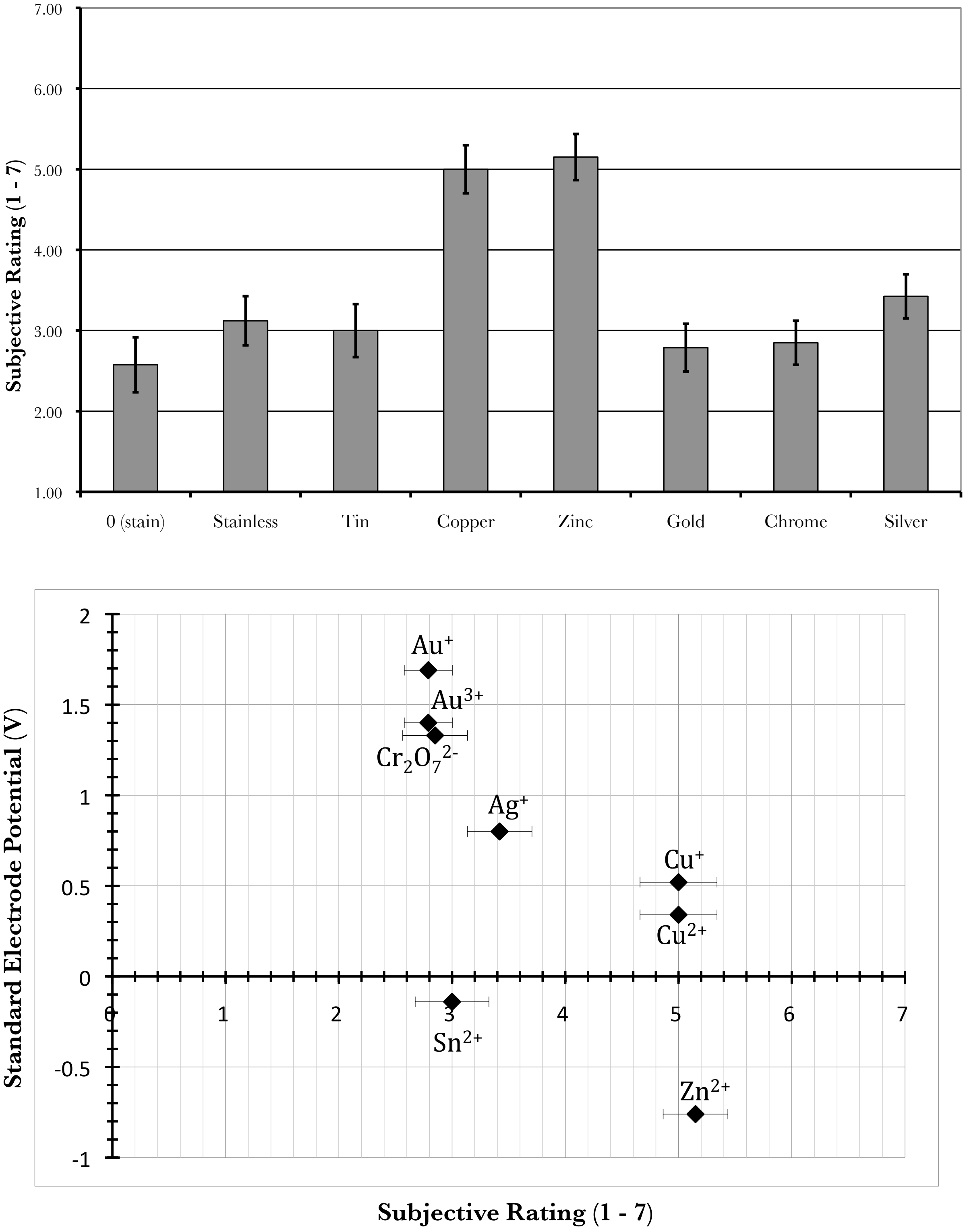
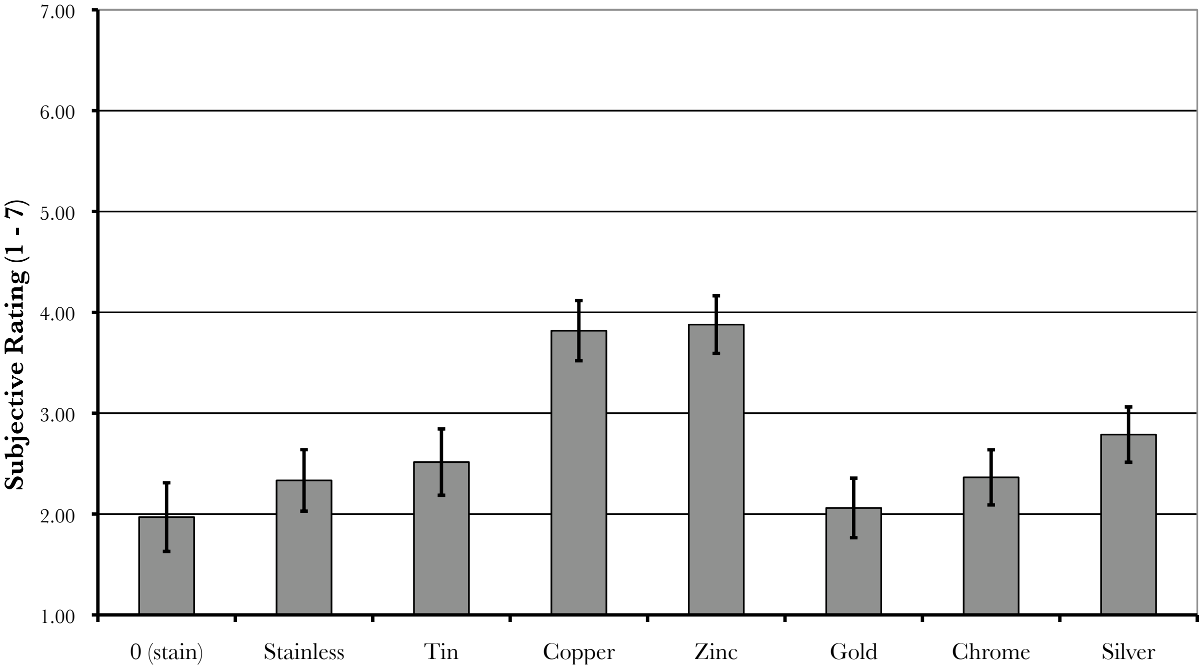


Figure 8.4: (top) The Subjective ratings of each of the eight spoons in response to the adjective *strong*; (bottom) Perception of strong plotted as a function of standard electrode potential.



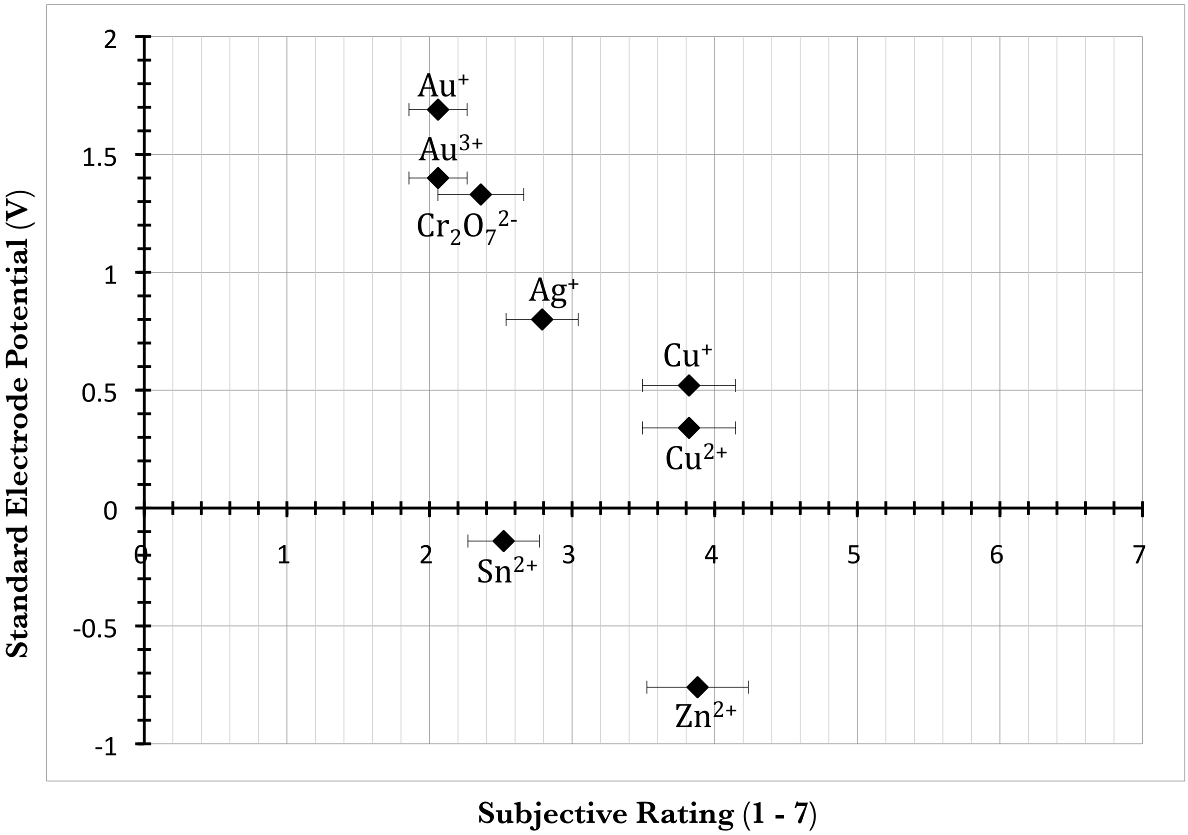
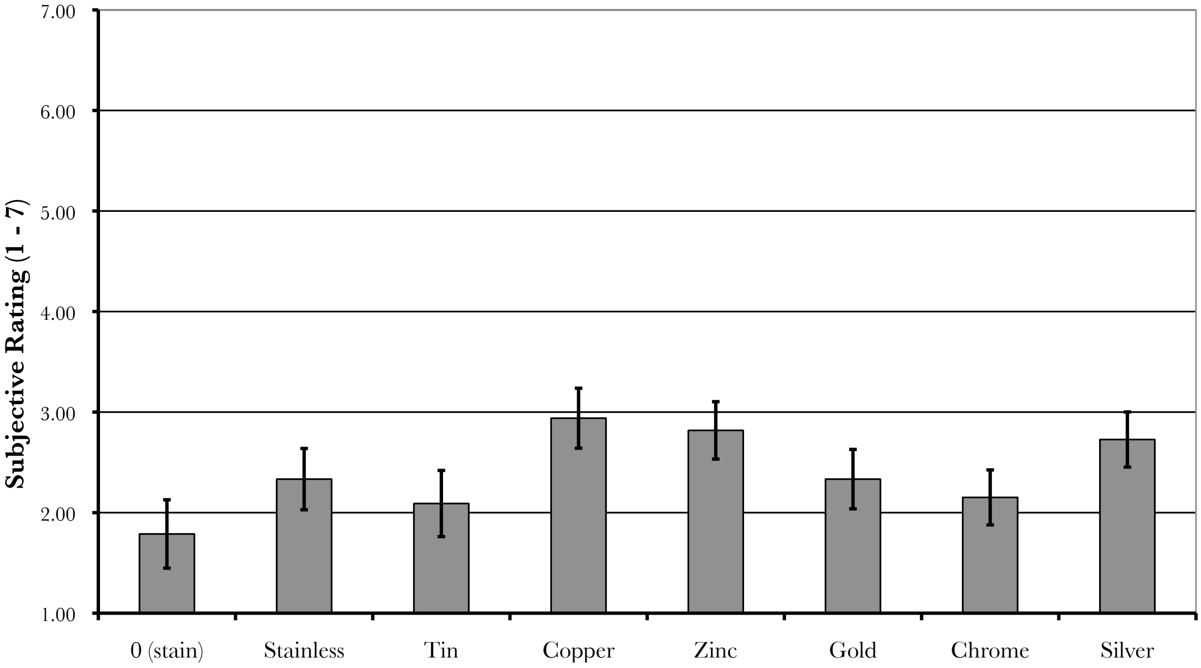


Figure 8.5: (top) The Subjective ratings of each of the eight spoons in response to the adjective *unpleasant*; (bottom) Perception of unpleasant plotted as a function of standard electrode potential.



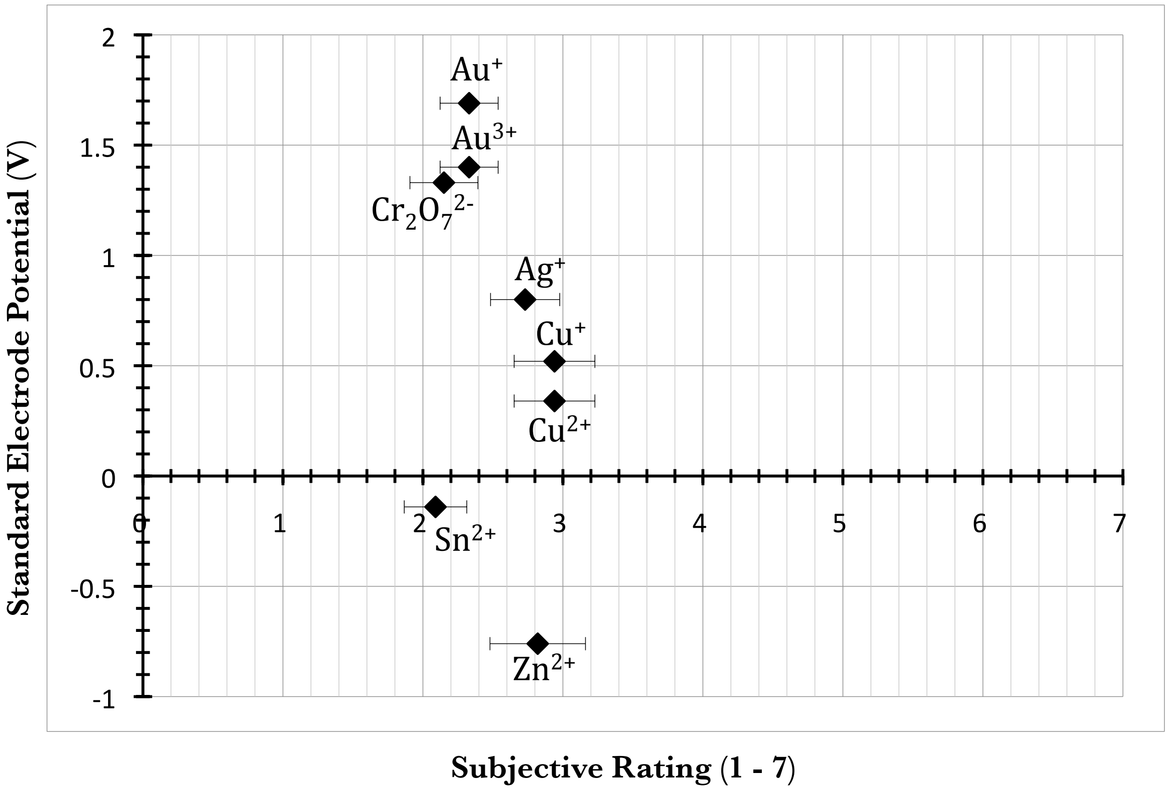
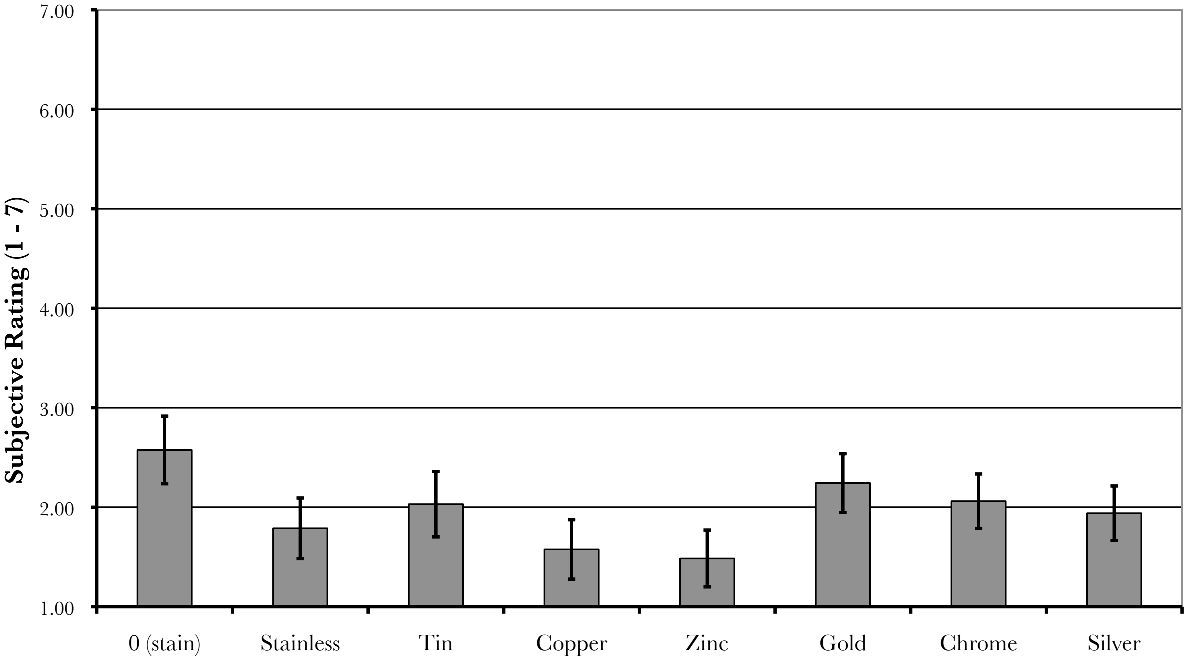


Figure 8.6: (top) The Subjective ratings of each of the eight spoons in response to the adjective *salty*; (bottom) Perception of salty plotted as a function of standard electrode potential.



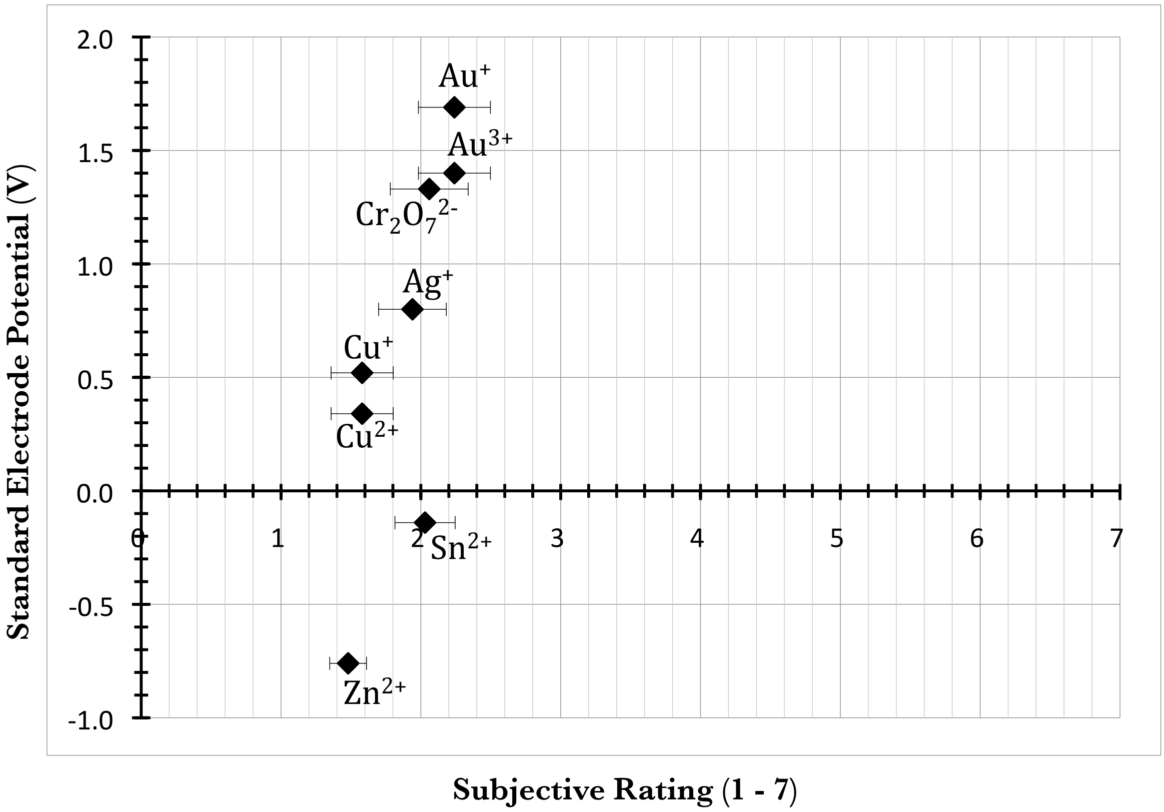
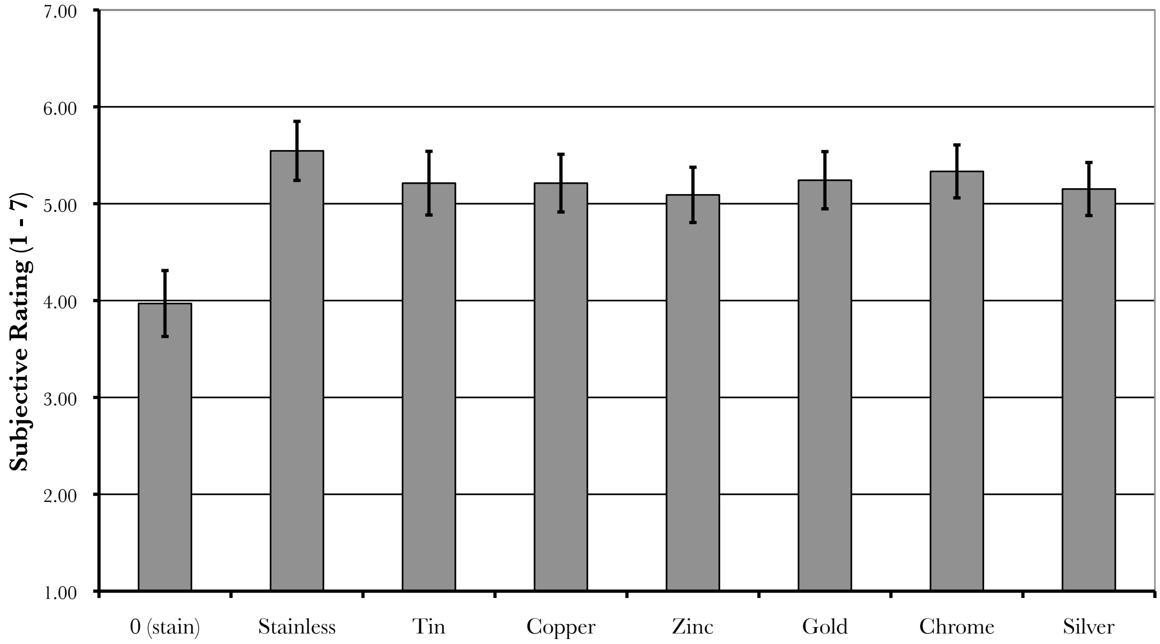


Figure 8.7: (top) The Subjective ratings of each of the eight spoons in response to the adjective *sweet*; (bottom) Perception of sweet plotted as a function of standard electrode potential.



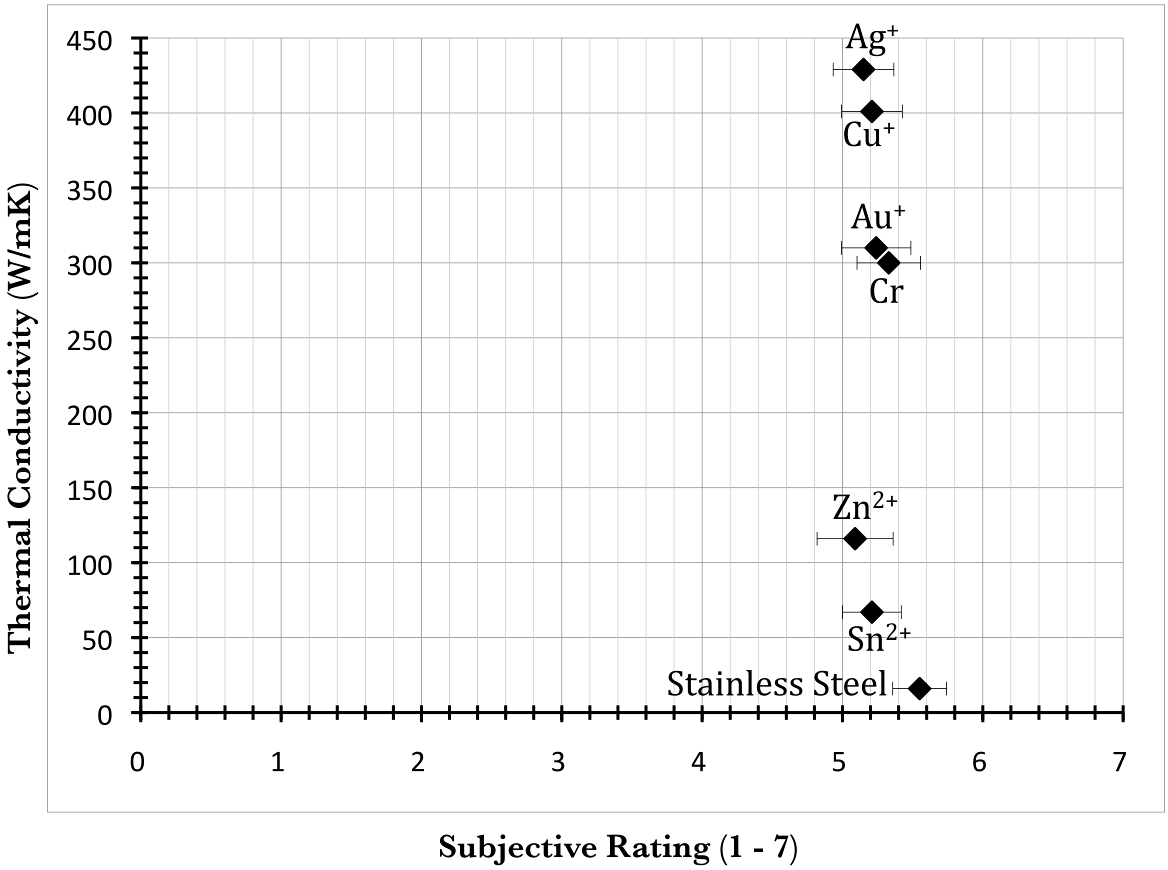


Figure 8.8: (top) The Subjective ratings of each of the eight spoons in response to the adjective *cool*; (bottom) The perception of cool plotted as a function of measured Thermal Conductivity.

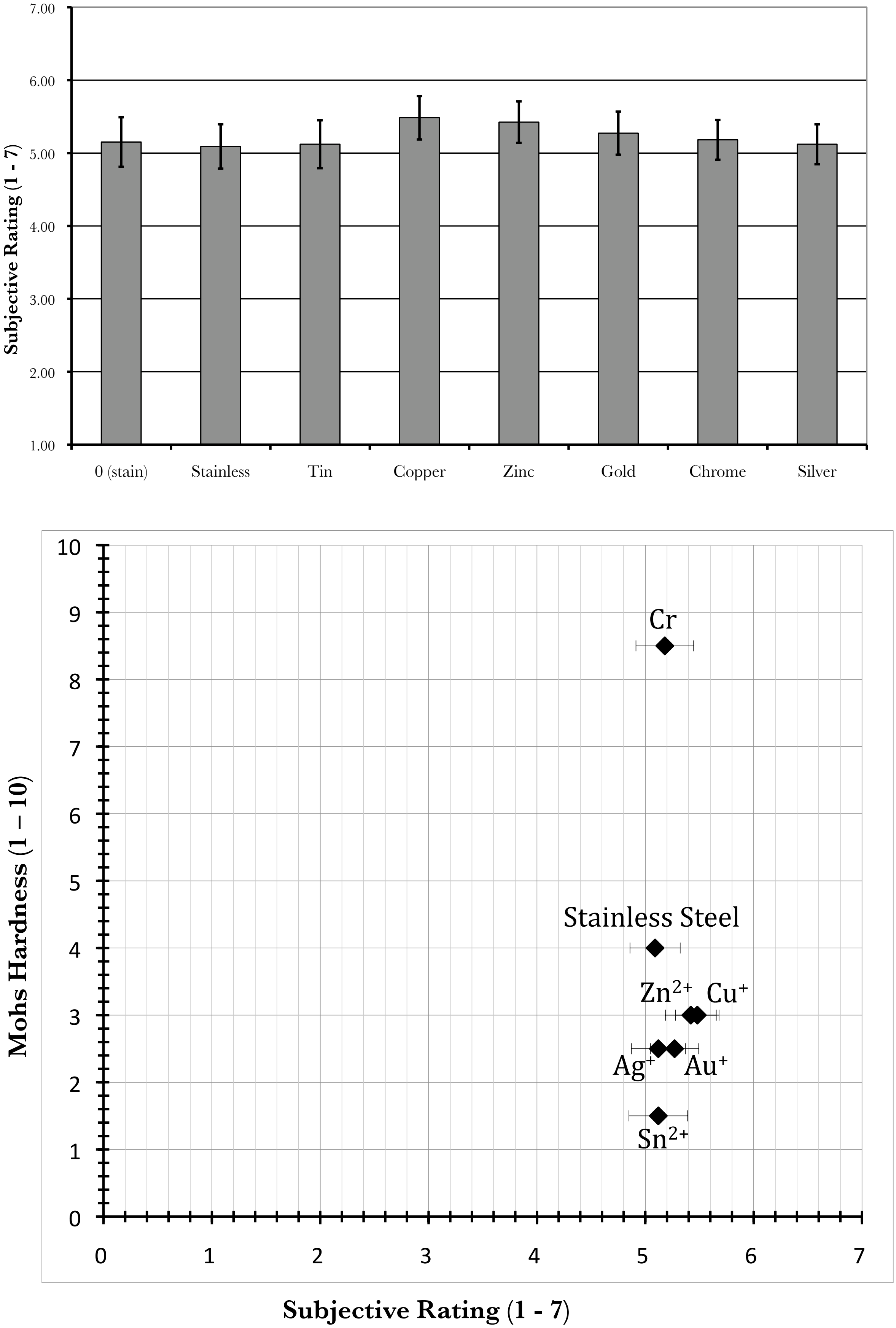


Figure 8.9: (top) The Subjective ratings of each of the eight spoons in response to the adjective *hard*; (bottom)) Perception of hard plotted as a function of measured Hardness.

8.3.3 Discussion

There is no obvious reason why standard electrode potential should be a good measure of taste sensations of metals. Nevertheless it does indicate broad trends of chemical activity which determine inertness and solubility which in this case correlate with the strength of some taste sensations. Standard electrode potentials appear to be good predictors of the tastes sensations of solid metals described as strong, unpleasant, bitter, and metallic. The zinc and copper spoons stand out in the plots in figures 8.2 to 8.7; as the most significantly strong tasting spoons, they were rated highest for the adjectives salty, bitter, metallic, strong and unpleasant. The gold and chrome spoons were frequently commented on by many participants as the most pleasant tasting of the spoons. On placing them in their mouths, participants would often say how they liked these spoons or were at least struck by the absence of taste. This is born out in the results with gold being the least unpleasant and strong tasting of the spoons, closely followed by chrome. The chrome spoon was rated as even less metallic in taste than the gold spoon, making it the least metallic tasting of all the spoons. The taste descriptors sweet (figure 8.6) and salty (figure 8.7) do not seem to be strongly correlated with electrode potential. Despite this, the gold spoon emerged with the highest sweet rating of all the spoons.

The standard electrode potential of tin ($Sn^{2+} + 2e^- \rightarrow Sn(s)$) is –0.13V, which according to the correlations in figures 8.2 to 8.5, would be predict that tin should be rated higher than copper for the taste sensations strong, metallic, unpleasant, and bitter. The fact that it consistantly scored lower than copper indicates either that dissolution in the aqueous pH neutral environment of the mouth is hampered in some way, perhaps by a stable oxide layer as in the case of chromium. The stable oxide layer of tin has been proposed to account for the success of tin plating of steel cans for the preservation the flavour and appearance of food (Blunden and Wallace, 2003), which has been common practice in the food packaging industry for more than one hundred years. Hong et al. (2010) have shown that the taste of astringency due to the presence of copper ions changed as a function of pH, as a result of lower solubility (Hong et al., 2010). In aqueous solution at pH greater than 2, Sn^{2+} will form Sn(OH)2, which has very low solubility (Duffield et al., 1990). Nevertheless tin has been shown to diffuse into canned food at appreciable levels dependant on storage conditions without unduely affecting the taste of the food (Blunden and Wallace, 2003) which is evidence in support of a hyposthesis that the gastatory taste recepetors in the mouth a insensitive to Sn^{2+} ions.

The silver spoon rated above all but the zinc and copper spoons for saltiness, bitterness and strength of flavour. It was some way behind the zinc and copper spoons however suggesting that despite being more pronounced than some spoons, that taste of the silver spoon was still subtle. Silver nitrate solutions are extremely bitter tasting, suggesting that the reason for the muted flavour of solid silver its low solubility in the pH neutral environment of the mouth.

Because it appeared as though the same spoons were consistently seen as metallic, unpleasant, strong and bitter, an unplanned analysis was performed for future hypothesis generation based on the question; "Are some of these adjectives correlated?" To test this statistically, each spoon was analysed by a Spearman rank correlation test using Prism 3.0. The adjective metallic was always found to be significantly correlated with strong and unpleasant (Spearmans $r > 0.36$ and $P < 0.05$ for all), and in all but one case (zinc, spearmans $r = 0.09$, $P > 0.50$) with bitter (Spearmans $r > 0.36$ and $P < 0.05$ for all others). Contrary to expectations, sweetness was never found to be inversely correlated with the adjectives bitter, unpleasant or strong ($P > 0.05$ for all). The hypothesis that might be derived from this unplanned analysis suggest that for the descriptor 'metallic' (at least when genuinely tasting metals), the descriptors 'unpleasant' and 'strong' may be redundant.

Conclusions

From plotting the average response to the spoons and statistically analysing the results, the following conclusions can be drawn:

- Despite the vast differences in their electrode potentials, both gold and chrome were considered the least metallic, least bitter and least strong tasting of the spoons.

- Zinc and copper were the most unpleasant, strongest, most metallic, most bitter, and least sweet tasting of the spoons.

- The following subjective evaluations were found to be subject to an order effect: cool, sweet, and salty. Where as the following subjective evaluations were almost certainly not affected by order: hard, bitter, and metallic.

- The adjective metallic was always found to be significantly correlated with strong and unpleasant, and in all but one case with bitter. Contrary to expectations, sweetness was never found to be inversely correlated with either bitter, unpleasant or strong. A surprise emerged in that the rating of hardness was invariably significantly correlated with coolness, although it was in two cases (for stainless steel and zinc) also significantly correlated with metallic. Salty was also always correlated with strong tastes, and sometimes with bitter or metallic tastes.

- The electrode potential results do not correlate with the subjective ratings of the spoons, though using electrode potential values that correspond to the oxides of the specific elements may provide stronger correlations.

8.3.4 Concluding Remarks

Taste is a complex phenomena that involves physical and psychological mechanisms that are difficult to measure and not yet fully understood. A number of conclusions have been drawn with regard to broad trends of the taste of some inanimate materials, with copper and zinc emerging as the most strong and unpleasant of the spoons and gold as the most palatable.

A key aspect of the work undertaken in this chapter, with regard to the thesis as a whole, relates to the isomorphic method of material-object creation being used to investigate aspects of materials science in a formal manner. To present material-objects as apparatus for scientific investigation demonstrates that they can not only embody the science of the materials from which they are made but also represent this science by generating designed and perceptible experiences of it. The spoons, as material-objects use their high object status and use value to present a clear agenda for experimentation, that of oral investigation into the effect of materiality of taste.

Future work on investigating the taste of inedible materials will aim to broaden the range of materials and introduce food stuffs that may or may not be altered by coming into contact with the materials of the spoons. A better understanding of the chemistry of each individual's mouth will also be an important part of future experimental procedures that attempt to investigate the taste of materials. To take pH readings of the participant's mouths before after and during the experiment, along with super taster test strips would go some way to improving this aspect of the experiment's design. It will also be crucial to obtain more information on the electrode potential and stability of the oxide layers that form on the surface of some of the spoons for it is these oxides, rather than the pure elemental material that are being tasted.

It is hoped that the work will result in a set of material-objects that will provide an experiential swatch of tastes. The form of the spoon will enable the swatch to serve real-world applications, with one spoon designated as 'the best' spoon for eating a boiled egg with, one designed for stirring tea, other for stirring coffee and yet another for eating yogurt for example. The work is already receiving attention from the culinary and design communities with Chris Lefteri's annual materials and design publication "Ingredients" featuring an article on the work, exclaiming that "if you stop and think about it, taste really does play an important role in many products.... [think about how] milk tastes different coming from a plastic bottle, carton or glass bottle” (Liden, 2009, p22).

Chapter 9

Experiments with Encounters

As outlined in section 3.4, an encounter is the physical coming together of people and material-objects within a framed experience. In each case, an encounter is a devised scenario that contains designed elements that serve to highlight specific aspects of the physical and conceptual performance of materiality through a relationship to the world of stuff and things. This chapter introduces three encounters staged with material-objects in the public domain over the course of this thesis. Each experiment is reported in terms of its set-up, event and aftermath. The set-up deals with the designing of each encounter, the event describes the activities and the aftermath provides a report on the outcomes of each experiment. The first section of this chapter looks a the *Speed Dating Materials* workshop, where participants are encouraged to physically interrogate and verbally articulate their experience of particular materials. The next section presents *The Essence of Fluorescence* exhibition that displayed a range of fluorescent material-objects, but where people were prohibited from touching them. The final section deals with the staging of four nights of material encounters with material-objects at Tate Modern, where the central premise was the facilitation and promotion of touch for the revelation of aspects of the science of materials. Conclusions are then drawn from the successes and failures of each encounter event.

9.1 Brief Encounters: Speed Dating Materials

Speed Dating Materials was an exercise devised to promote the exploration of materials through physical manipulation and verbal description. The term *Speed Dating* was used as it is a type of activity synonymous with swift interactions, first impressions and instinctual selection and rejection and would thus conjure up the brevity and energy of the activity as applied to materials.

The event of *Speed Dating Materials* was staged many times as a workshop for a maximum of ten people over the course of this this PhD. It has been run for a wide variety of people at a number of different locations. Participants have included groups of GCSE pupils aged 15 and 16, MA students studying industrial design and professionals from both the arts and the sciences. Locations have ranged from the Materials Library, meeting rooms at design practices, studio spaces within art colleges and resource areas in public art galleries. The following looks at a typical *Speed Dating Materials* workshop run for ten participants around a large conference-style table.

In accordance with PAR protocol (see section 4.1.2) all participants were informed of the research nature of the exercise and can thus be regarded as researchers, due to the very fact of their participation (MacIsaac, 1996, p4) (O'Brien, 2010, p5). In doing so, the learning experience of each participant is foregrounded as central to the outcomes of the event (Ferrance, 2000) as an experience, where curiosity, discovery and multiple types of materials knowledge were to be celebrated.

9.1.1 Set-Up

Ten black file boxes with flip-up lids were purchased and a label printed for each lid. The labels displayed each individual box's number (between 1 and 10) and the instruction "do not open until instructed to do so". Inside each box three items from the Materials Library were placed (examples of four boxes with contents from one *Speed Dating Materials* workshop can be seen in figure 9.1). When selecting items for inclusion, care was taken to ensure that the contents were not overtly recognisable or identifiable and afforded a range of tactile experiences. Consideration was given to the following in order to ascertain if the range of items included would afford a selection of experiences, though answering in the affirmative was not always required;

a. In what ways is the item remarkable? (eg: haptically, visually, mechanically, conceptually?)

b. Does the box contain three items of varying interest?

c. Can an item be identified as an object with a specific function? (eg: toothbrush)

d. Does the item have a hidden story or function that can not be revealed simply by handling?

Once the contents for each box had been finalised the boxes were closed and placed in non-numerical order around a large table. In front of each box a chair was placed, creating a table setting of box and chair, ready for the participants to each take a place. A representation of this arrangement can be seen in figure 9.2. A space would be left at the head of the table

Figure 9.1: The inside of four file boxes from a *Speed Dating Materials* workshop showing contents –3 items per box.

for the author as workshop leader to sit and a spare file box would be place here for possible demonstration purposes.

9.1.2 Event

Once the participants enter the room they are instructed to take a seat in front of a box and reminded not to open the box until instructed to do so. Participants are then informed of the task that constitutes *Speed Dating Materials*: to physically encounter and explore the items they find inside their boxes one by one, exhaustively vocalising their thoughts and reflections. They are told that there are three items within each of their boxes and that they should talk for one minute about each item before picking one material from within their box that is their favourite and explaining the reasons for this choice.

Before commencing, the participants are reminded that there is no ‘correct’ answer or response to any of the items they will find and they should consider this an exercise in generating free responses to, associations with, and discoveries of, materials. They should not feel afraid to touch, smell and possibly even taste the materials if this will help them ‘get to know’ them

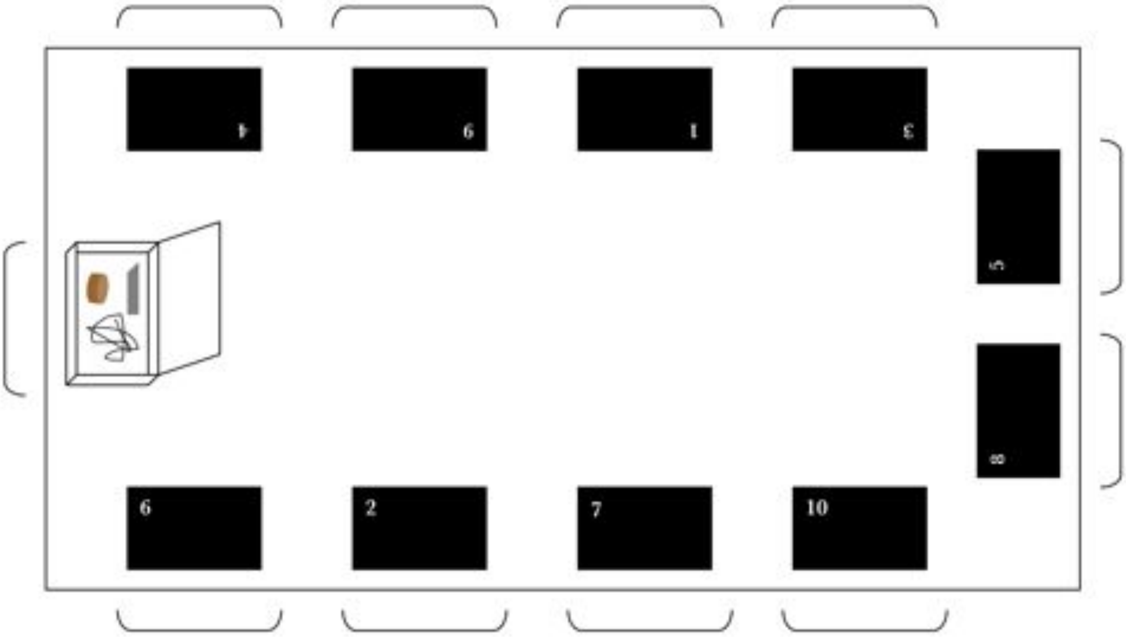


Figure 9.2: Table set for *Speed Dating Materials*.

better and decide which one is ‘for them’. The participant with box number one is then asked to begin.

Once all participants have gone through the contents of their boxes, vocalised their responses and selected the material they wish to ‘date’, the discussion is opened up and the group are encouraged to investigate, explore and discuss each other’s objects and the reactions and observations the task brought to light. Common themes in the reactions, opinions, pleasures and displeasures participants found in their material-objects are recognised and a new appreciation of the role, power and performance of a material is formed.

On occasions the *Speed Dating Material* workshop has been done by unsupervised groups. In such instances the following text is provided to initiate the task:

> *Still looking for your perfect match? Anxious about what might be left on the shelf? Tired of the same old polystyrene? Then try Speed Dating Materials!*
>
> Take your place in front of one of the boxes. Starting with box number one, spend 60 seconds with each item within it in turn. Whilst exploring each item, tell us about your experience. Vocalise what is happening physically. Say what you like, don’t like... Be opinionated, make snap judgements, go with your first impressions.
>
> After making your way through the three samples, you must say which one is for

> you. Which material takes your fancy... which one would you want to get to know better... which one will be your date for the evening and why?
>
> It is now the turn of the person with the nest box.

Encounters:

The following are transcripts of specific encounters with the *Speed Dating Materials* task carried out by a group of adults from a cross section of art and science backgrounds. All speech is made by the participant except that prefaced by 'ZL:' which was made by the author. Observations in square parentheses derive from field-notes made by the author during the workshop.

Encounter with Box 1:

[Inside this box is a rubber egg, a lump of silicon and a section of honeycomb aluminium –visible in the bottom right box of figure 9.1.]

"Uumm" [Participant lifts the lid of the box and surveys the contents.]

"An egg... [picks up the egg] ...made of rubber. It's quite soft... smooth. The colour is a bit weird. I like the shape. It fits nicely into the palm of my hand."

[This verbal description is accompanied by the participant handling the item with both hands, digging the nail of one finger into the surface of the material, clenching their fist around the egg and squeezing it.]

"It would probably bounce..." [The participant stands up and moves away from the table before bouncing the egg onto the floor. The egg ricochets unpredictably around the room.] "...yep... I expected that." [Retrieves the egg and sits back down.]

"Eerrr... that's probably a minute. [Puts egg back in box and picks up the honeycomb aluminium.] "It's very light. Surprising. I thought it was going to be heavier. It's lighter than the egg. Shiny. A bit boring. [Studies the object from all sides.] Quite sharp at the edges. If I look down inside it there are lots of reflections. Hold it back a bit more, it's like having a fly's eye. All these hexagons.... I wonder how it's made. I would probably extrude it but it is very thin. [Begins strumming the side of the object as if it were a guitar.] I like the sound it makes when you run your finger along the side. If I tap it, it's not as good. I can squeeze it this way a bit... it will compress. But not so much this way. Ooo.. it's hard and quite sharp. It has left hexagon impressions on my hand. I don't know what you would use it for."

[The verbal description is accompanied by numerous physical exploratory actions. Once the participant has finished speaking they take a final look down the inside length of the honeycomb aluminium before replacing it the box and lifting up the silicon.]

“Another light one. Well, light for a rock. Well, I think it’s a rock, or a crystal, or some sort of metal? It’s sort of shiny. I don’t really know what to say about this one.”

[Participant pauses to study the item more closely, turning it round, rubbing it, trying to scratch into it with their finger nail.]

“I like it. I’m trying to imagine finding it in a landscape. Could you clean coal and varnish it to produce this effect? I don’t know what it is. It does not really *do* much.”

[They put the silicon back the box.]

“I have to choose one?”

ZL: “yes”

“I would choose the egg because it’s fun and it’s the nicest to hold. Comforting somehow. Companionable. Friendly.”

Encounter with Box 2:

[Inside this box is a tile of floated glass, a bag of jelly wax and a section of non ridged honeycomb aluminium –visible in the bottom left box of figure 9.1.]

“Ok, first up... [picks up the glass tile] ...some glass. Very thick and heavy. Cold. [Places the tile against their cheek.] Smooth. The edges are nice, they seem to have been sanded. This would make a very thick window.”

[The participant holds the tile up to the light and rotates it back and forth.]

“I wonder if it is the sort of glass used in massive aquariums. It’s an interesting colour... transparent but somehow green.”

[Puts the glass back in the box and picks up the non-ridged honeycomb aluminium.]

“Wow, that’s surprising. I was not expecting that. It’s metal but it’s very wobbly. I like this. [Plays with the item, bending it back and forth, wobbling it, letting it drape over their hand.] It’s not a spring but it is like one of those things that go down stairs... a slinky. I just want to keep it moving. It stretches and I can also squeeze it to make it more compact. [Holds it up to the light] You can sort of see through it. There are tiny little holes or gaps. It’s great.”

[Manipulates the material some more before returning it to its box and picking up the next item.]

“And my last thing is a bag of what feels like a gel. Can I open it?”

ZL: “Yes, go for it.”

[The participant carefully opens the bag and prods the material.]

“It’s sort of wet... [takes hand out and rubs their fingers together] ...and oily... [lifts bag to their nose] ...and smells kind of solventy. I think this is a wax but it’s strange that it’s not a solid. I'm not sure I like this... [plays with it through the bag] ... though it's strangely satisfying. I guess I'd have to be in the right mood for this one."

[Puts the gel wax back in the box and surveys the contents.]

"So... I think this is the one for me. [Picks up the non-ridged honeycomb aluminium.] It's fascinating and unexpected and I would enjoy spending more time with it."]

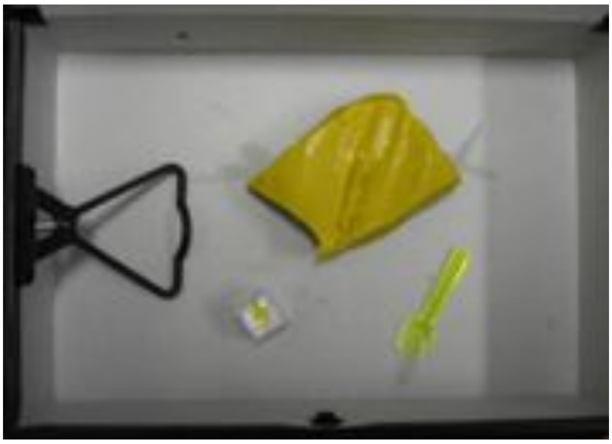


Figure 9.3: Speed Dating Materials Box 7, contents: re-mouldable rubber, amber, live-edge acrylic ice cream spoon.

Encounter with Box 7:

[Inside this box is a lump of re-mouldable rubber, a piece of amber and a live-edge acrylic ice cream spoon –visible in figure 9.3.]

[Participant 7 opens the box]

"Ahh, they're all the same colour!"

[Picks up the ice cream spoon.]

"I know what this is. It's a little shovel for eating ice cream. I guess you could eat other things with it but you wouldn't get very much up at a time. It would be funny to try and eat properly with it, perhaps with one of the wooden fish and chip forks you can get. It's like a little spade. You could try digging with it but it's probably not strong enough to cut through much. I don't especially like the colour, it's too artificial to be around food. I guess it could be fun for children or something."

[Puts the spoon into the box, picks up the acrylic box containing the amber.]

"I'll go for this one next. [Opens the box and carefully lifts out the amber.] This is amber. Quite light in colour and it's got something in it. [Holds it up to the light and peers closely at the item.] Some sort of insect like in Jurassic Park. I used to have an amber necklace but it was much darker in colour than this. I wonder why it comes in different colours. This seems very light but maybe it is because it is thin. I'm not sure. It's smooth and plastic like. Actually, it could be a fake I suppose. I wouldn't know how to tell. [Brings the amber to their lips and gently taps it against their teeth.] Uuumm. I'm going to go with amber as putting it this little box implies it is precious in some way. It's a sweet shape and I like that the material has an obvious age otherwise it would not be here, as in it would not have formed."

[The participant puts the amber back in the acrylic display box then returns it to the box file before picking up the re-mouldable rubber.]

"Right, I was saving this one until last as it the biggest and looked the most exciting when I opened the box. It's a bit slimy and has left some sort of residue inside the box. It seems to be giving off an oil. I wonder if it smells. Errr, I don't much care for it. I think it's rubber but I don't know what it's used for. It's been hacked around and there are cut marks here and here. I think it would bounce or could cushion a fall. It puts me in mind of cold solid custard."

[Puts the rubber back in the box.]

"Though I like the rubber and the little shovel, I like them less than the amber which seems more special to me. It has a history that appeals and I can think about it more deeply."

9.1.3 Aftermath

The consequences of participating in a *Speed Dating Materials* workshop can vary from person to person, depending upon their prior level of material appreciation, curiosity and knowledge. In general, the majority of participants discover a material that is new to them as well as new things about materials they previously were familiar with. Participants learn about their emotional and physical responses to materials and, in attempting to express their experience of a material in words, explore the often non-verbal, indescribable qualities of some materials. In many cases people were surprised to discover how much they had to say about a material and through the course of the workshop, realised how much material knowledge they posses. A sense of trusting one's senses and the expertise of one's own touch emerged from the participants in *Speed Dating Materials* who discovered ways to interrogate materials that confirm their eyes and hands as sensitive interrogative instruments. As a result, many participants take away with them a renewed enthusiasm for materials and playful handling as a means of material discovery and thinking.

It also becomes clear through the course of a workshop how many different responses to the same material there can be, as well as how similar. The communal aspect of experience, having to verbalise their responses and share thoughts, opinions and sensations with others, meant that they were pushed further and formed more fully than they might have been if the participants had simply been alone with the same materials not under a requirement to perform. What may have flitted across their mind on picking up a material is now dwelled upon and formed into words, expressed with gestures and extended into a shared experience.

The limited time in which participants have to respond to a material means that they are forced to think quickly and respond with immediacy. In some cases participants found it more difficult to speak for the full minute about some of the materials. Even if they could not find anything to say, the constraints of the task meant that they spent the time handling the material and being observed by the others around the table. For some this experience was uncomfortable and they were relieved to move onto a material which provoked from them a more animate response.

The nature of their physical interactions, as described in the above encounters, revealed varying levels of comfort that participants had with physically investigating materials. Some thought nothing of putting a material to their lips or cheek, hitting the sample on the table or tenderly caressing its contours. Others simply held the sample in their hand, casually rotating it as they spoke. The form and nature of the material appeared to influence this as much as the investigative style of the participant. If a material had a degree of opacity, it was more than likely that it would be held up to the light, or if a material felt elastic, chances were that most people would try to bounce it or stretch it.

As the deviser, curator and host of the *Speed Dating Materials* activity, I too gain new knowledge and discover connections between materials through the course of a workshop. Each participant brings a fresh pare of eyes and hands to the task and through their actions and comments, it is possible to see the contents of each box in a fresh light every time it is encountered. Repeated experience does count for something, however. I have come to anticipate the nature of possible responses to particular materials, predicating which materials elicit particular responses and testing material combinations in the curation of future Speed Dating boxes.

Testament to the success of *Speed Dating Materials* is the fact that it has become a regular feature on the BA and MA Design courses at both Goldsmith's and London's South Bank Universities. Each year I am invited to run the workshop with students as part of the material education and skills development process. Not only does the workshop command repeat performances but people who participate in it have gone on to run their own versions of the workshop in their respective communities. As a format it has proved successful with ages 8 to 80 as well as with materials professionals and amateurs alike and serves to celebrate the power of the physical encounter.

9.2 The Essence of Fluorescence

In the first quarter of 2006, London's Hayward Gallery hosted a retrospective of the work of the American artist Dan Flavin (1933 –1996). Flavin's work is primarily characterised by his conscious use of fluorescent light and fluorescent tubes of varying colours to generate a variety of optical effects. In order to highlight and communicate something of the science at play within the work of Dan Flavin, the Hayward Gallery commissioned a response to the exhibition from the Materials Library. The result of this commission was the creation of *The Essence of Fluorescence*; a cabinet of fluorescent curiosities that aimed to explore the phenomenon of fluorescence and reveal something of its subtle dynamism and animal, mineral, and object nature. The commission was an opportunity to test out how to display material-objects and represent particular phenomena in an environment where touch was prohibited and there was no informed supervising presence.

9.2.1 Set-Up

Two identical cabinets were designed by the author and then built to order by Exhibitbuild. A plan for one of the cabinets can be seen in figure 9.4. All surfaces were painted black with matte exhibition grade paint. Each cabinet was designed with nine glass fronted recesses, in which items could be displayed under three different lighting conditions; white light, ultraviolet light and no light (darkness). The lights (two adjacent rows of LEDs that spanned the width of the window and ran along the top inside edge of the glass, hiding them from the view of the visitor) were programmed so that only one window in each cabinet was illuminated at any one time. The illumination sequence for each recess began with ten seconds of white light, then changed to ultraviolet light for a further ten seconds before resting on darkness. The order of illumination was sequential; left to right along the rows, starting with the top row and moving down. The subsequent window's white lights only came on after the previous cabinet's ultraviolet lights went off.

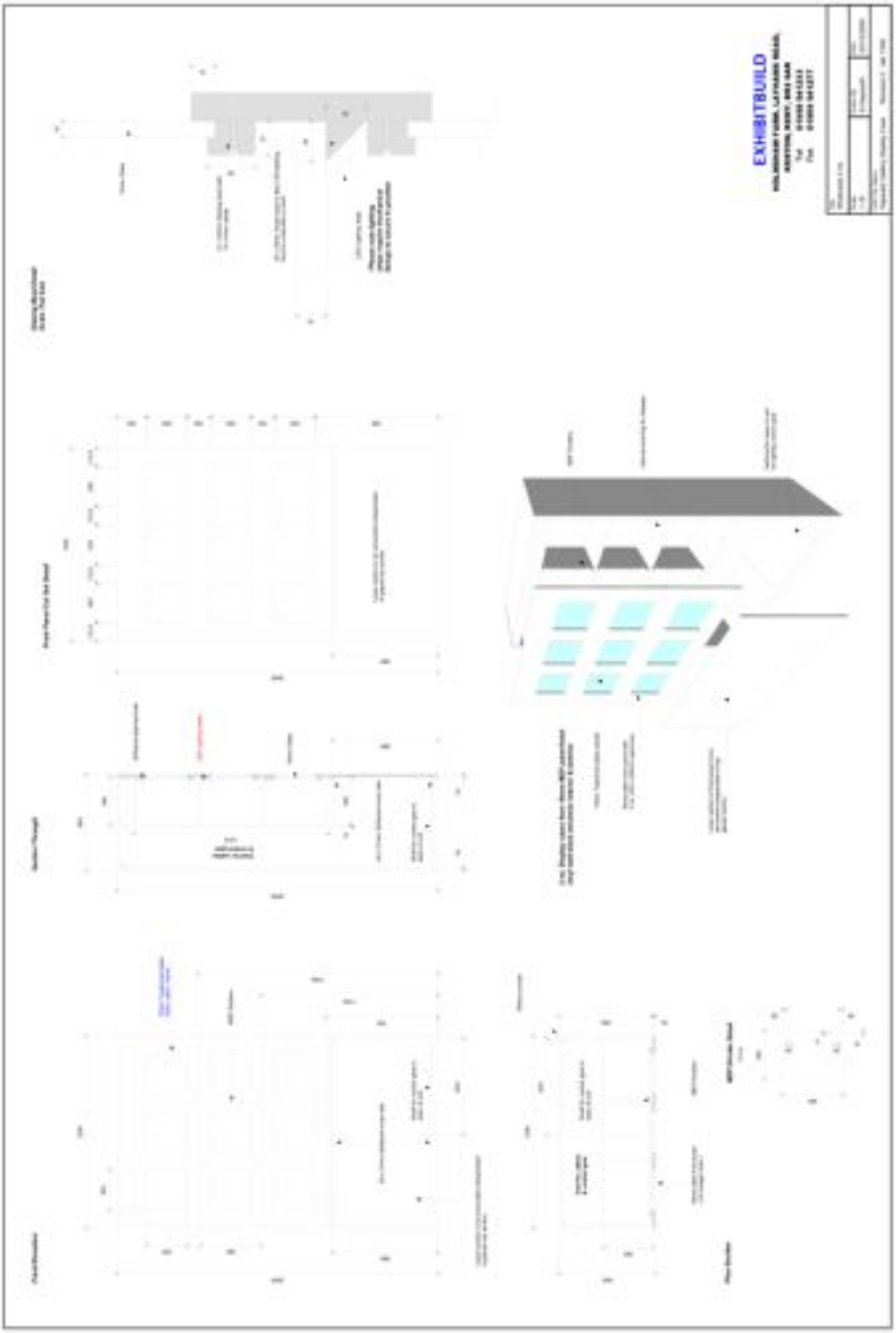


Figure 9.4: Plans for The Essence of Fluorescence cabinet.

Research was undertaken into the breadth of materials that were known to fluoresce. Both artefacts and information were gathered that pertained to the topic. The phenomenon of fluorescence became the lens through which the material world was interrogated and by which the act of collecting was focused. The following graphic in figure 9.5 outlines the final list of items selected for inclusion within the cabinets and their designated location. The preceding description of each window's contents serves to illustrate both the range of items that were collected for display and the stories that were gathered along with them. Images of the items can be viewed on the Materials Library website[1].

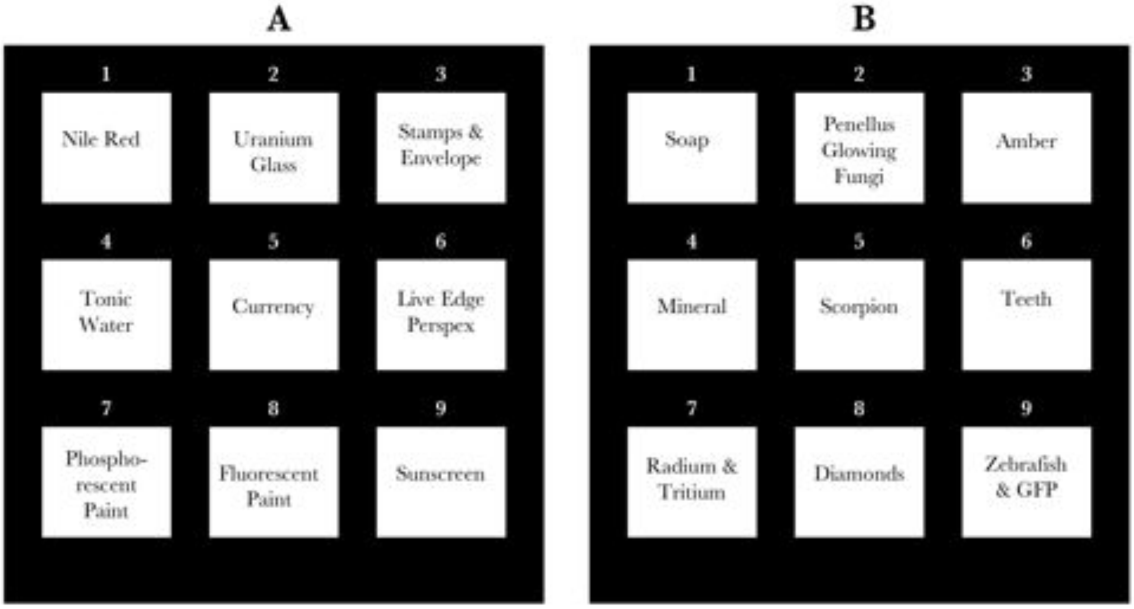


Figure 9.5: The Essence of Fluorescence cabinets A and B with listed contents, windows 1 to 9.

Cabinet A

A.1 Nile Red

Contents: 5 10ml vials of liquids of differing colours.

Comment: Nile red is an organic compound that is strongly fluorescent and can be dissolved in a number of different solvents to produce solutions of differing colours. The nile red molecule behaves differently in differing environments (solvents) and this behaviour is expressed through the emission of light in discrete parts of the visible light spectrum. For example, if one dissolves

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[1] http://www.materilaslibrary.org.uk
For the Flash animated version see http://www.materialslibrary.org.uk/MaterialsLibrary/events/essence.htm

nile red in water, the solution takes on a strong blue colour, where as in toluene, a solvent commonly found in paint strippers, the solution takes on a yellow colour.

This ability of nile red to sense its environment is what makes it such a useful biological imaging tool as it reveals information about the sample it is exposed to, through the different colours it expresses. What nile red is sensing are the differing polarities of the solvents. The higher the polarity of the solution, the bluer the fluorescent emission; the lower the polarity of the solvent the redder the fluorescent emission. The polarity of a solvent refers to the charge of its molecules. To talk of a specific polarity of a solvent is to describe what type of solid can be dissolved within it. As a rule, like dissolves like: highly polar solvents are hydrophilic (water loving) and will dissolve hydrophilic substances; where as lipophilic (oil loving) solutions dissolve lipophilic solids.

A.2 Uranium Glass

Contents: A fruit bowl cast from uranium glass.
Comment: The glass of this fruit bowl, sometimes called Vaseline Glass, contains traces of uranium oxide and originates from Australia C.1950. The uranium is what gives the glass a yellow green appearance under white light and provides the vivid green fluorescents under ultraviolet light. The presence of uranium also means that it is a mildly radioactive object.

A.3 Stamps and Envelope

Contents: An envelope addressed to The Materials Library with two stamps fixed upon it.
Comment: Fluorescence in philately is a recognised dimension to the appearance of some stamps and helps with identification and the verification of postage. On this envelope the left hand stamp fluoresces a greenish-yellow under ultraviolet light. There are also post-markings running along the lower portion of this envelope that have been printed by the postal authorities in orange fluorescent ink. The combination of vertical lines of varying heights and groupings impart information (rather like a barcode) that tells of the date, time and location of the letters posting. The use of fluorescent inks allows the marks to be read clearly by a machine under ultraviolet light and not confused with other markings that may be on the envelope.

A.4 Tonic Water

Contents: A 100ml bottle of Shweppes Indian Tonic Water, unopened.
Comment: The active fluorescent ingredient within tonic water is quinine. This organic com-

pound is extracted from the bark of the Cinchona tree and is responsible for the bitter taste of tonic water, as well as the liquid's anti-malarial properties. The brightness of light emitted by quinine, when exposed to ultraviolet light, is so reliable and stable that quinine is used as a fluorescent intensity standard, against which levels of fluorescents are measured and machinery calibrated.

A.5 Currency

Contents: A £20 note (BPS).
Comment: Ultraviolet light is used to detect counterfeit bank notes in many of the currencies of the world. Genuine notes contain markings that are invisible under everyday white lighting conditions but when viewed under ultraviolet light, a variety of symbols and patterns are revealed. In the United Kingdom, bank notes have their particular denominations inscribed upon them in inks that become visible under ultraviolet light. For example, a ten-pound note reveals a glowing 10 and a twenty-pound note contains a fluorescent 20.

A.6 Live Edge Perspex

Contents: Three Paper Mate propelling pencils from the Sharp Writer Neon collection.
Comment: The propelling pencils within this window have been made out of a polymer that is commonly called live edge Perspex and contains fluorescent dyes. The intensity of light given off by the polymer is greater at the edges, for the light is gathered along the length of the material and emitted at the ends where the surface area is reduced and the fluorescent effect focused. Whilst the mechanics of the pencil propels graphite to the tip, the material it is made from propels light in the same direction.

A.7 Phosphorescent Paint

Contents: One 500ml jar filled with phosphorescent paint.
Comment: Some fluorescent materials do not give out visible light immediately but act as light stores, giving off visible wavelengths for a period of time after the incoming light source has been turned off or withdrawn. This phenomenon of slow emission is called phosphorescence and is what gives us ‘glow-in-the-dark’ paints. The phosphorescent pigments in such paints contain fine crystals of zinc sulphide with copper added as an activator that allows the crystals to absorb light and slowly emit it over time.

A.8 Colour Swatch of Fluorescent and Non-Fluorescent Paints

Contents: Samples of paints available from Bristol Paints bound together in a swatch, fanned out evenly to show the array of colours.

Comment: Paints that may appear similar under white light have their differences revealed under ultraviolet light as those paints that contain fluorescent pigments leap to life, emitting visible light in a variety of lurid colours.

A.9 Sunscreen

Contents: A sheet of card containing fluorescent whitening agents sprayed with sunscreen.

Comment: Sunscreen acts as a barrier to ultraviolet light, preventing the harmful UV rays from the sun burning our skin. When viewed under white light, the cream is invisible against the white card but when the lighting condition switches to ultraviolet light, the area where the sunscreen has been applied becomes visible. The cream prevents the paper from coming into contact with the ultraviolet light and in turn, prevents the ultraviolet rays from being reflected back as visible fluorescence, leaving the sunscreen soaked areas black (see figure 9.6). In effect, the area where the sunscreen is, appears black under ultraviolet light because ultraviolet rays are being prevented from touching the paper.

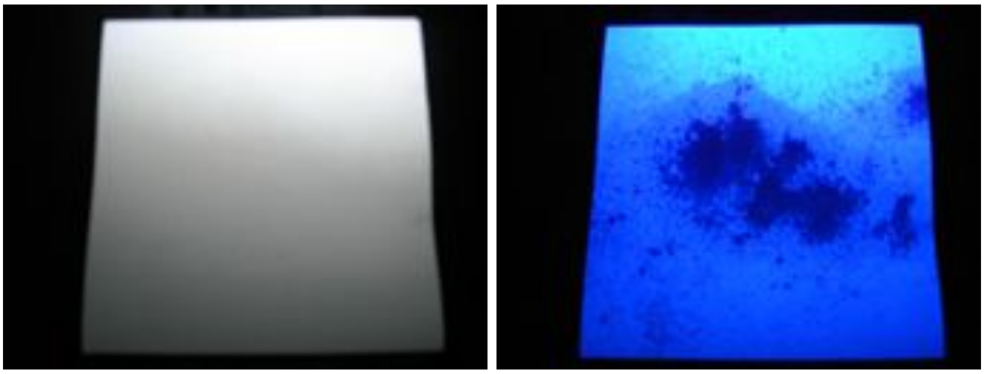

Figure 9.6: A sheet of white card that his been sprayed with sun protection factor (spf) 25 sunscreen, viewed under white light (left) and then ultraviolet light (right) within the The Essence of Fluorescence display.

Cabinet B

B.1 Soap

Contents: A bar of soap from Lush.

Comment: When hunting for fluorescent objects for this display, the number of items we came across in our bathrooms was rather alarming. A combination of bacteria and cleaning products mean that there lurk all kinds of natural fluorescing growths and artificial whitening agents. The soap on display contains peppermint, lavender and tea tree oils with alkanet extract. It appears pink under white light and a fluorescent greenish colour under ultraviolet light.

B.2 Fungus

Contents: A 10cm diameter petri dish containing a fungal growth.
Comment: This Panellus stipticus fungus has been cultured on agar jelly but naturally grows on wood, producing bodies similar to oyster mushrooms when in fruit. This type of fungus has been reported in the wilds of Britain but its delicate fluorescent glow is rarely seen.

B.3 Amber

Contents: A lump of roughly polished amber approximately 4 x 3 x 2cm.
Comment: Amber is the fossilised resin of trees that grew between 30 and 90 million years ago. Resin is excreted from trees at points of damage, occasionally trapping insects, dirt and biological matter as is oozes from a gash in the tree or a point where a branch has been broken off. Artefacts found within amber provide scientists with a valuable window on the past. In cases where biological matter such as flies or seeds are found, information like DNA can be extracted to providing data on prehistoric life and the environmental conditions that supported it.

Amber is often used in jewellery and is prized for its beauty but also has a number of properties that are less obvious. If one rubs a piece of amber with a material like wool, a static charge is generated as electrons are transferred from the wool to the amber. This means the amber becomes negatively charged and enables one to pick up small pieces of fluff or feathers with the hard resin. Another surprising property of amber is that it fluoresces green under ultraviolet light. This is due to the sulphur levels that are found within amber and the higher the sulphur content, the more vivid the fluorescence.

B.4 Minerals

Contents: Three naturally occurring minerals. From left to right: Adamite from Mexico; Franklinite and Willemite from New Jersey, USA; Manganocalcite from Peru.
Comment: In all of these rocks, ultraviolet light reacts with chemicals within the minerals, causing them to fluoresce. In Adamite, which is chemically zinc arsenate hydroxide, trace amounts

of copper and uranium give a greenish appearance and the fluorescent qualities. The second rock is a combination of Franklinite (zinc, iron, and manganese oxide) and Willemite (zinc silicate), two minerals that commonly form together and are found at Franklin, New Jersey. These deposits are considered by geologists to be some of the most wondrous and unique ever discovered, with the dull black and brown grains transforming into an array of green fluorescents under ultraviolet light. The right hand mineral, Manganocalcite (manganese and calcium carbonates), has been polished into a smooth lozenge and appears a milk pink colour under white light but transforms into a bright pink fluorescent orb under ultraviolet light.

B.5 Palamnaersus Scorpion

Contents: A Palamnaersus scorpion from New Mexico, USA. Approximately 15 x 10cm.
Comment: The thin outer layer of the Palamnaersus scorpions exoskeleton contains a protein that fluoresces a delicate green. In white light the scorpion is clearly a shiny back colour, whilst under ultraviolet light the exoskeleton displays a mottled green fluorescence with greater concentrations of fluorescence at the joints of the scorpion.

B.6 Teeth

Contents: A set of milk teeth from the mouth of Zoe Laughlin, lost/extracted between the ages of 6 and 12.
Comment: The structure of a tooth is such that it can be divided into three areas; the outer coating of enamel which caps the tooth above the gum-line; the dentine that forms the main body of the tooth; and then the inner pulp of the tooth. Enamel is the hardest substance in the human body and is made up primarily of calcium and phosphorus crystals. These elements give teeth an iridescent quality and cause them to fluoresce blue under ultraviolet light and appear whiter than white in sunlight. Once the enamel has formed, the individual level at which one's teeth fluoresce has been set. If one has a replacement false tooth, there will nearly always be a distinguishable difference between the new tooth and ones own teeth, as the fake tooth will fluoresce differently if at all. Dentine also fluoresces but in a different colour to enamel. The fluorescence of dentine is green and is visible in areas where cavities in the enamel reveal the dentine underneath, or in the root of the tooth where enamel never forms.

B.7 Watch Faces and Radium

Contents: Two exposed watch faces without hands.
Comment: During the Second World War, the military were searching for something that would illuminate the dials of instruments within the cockpits of aircraft that would allow the pilot to read them but not light up the cock-pit and make the plane visible to the enemy at night. The solution that was adopted by many Air Forces was to paint the figures of the dials with paint that contained either Radium or Tritium, capitalising on the elements' phosphorescence. This paint was also used on the faces of watches worn by service men that needed to tell the time in the dark.

B.8 Diamonds

Contents: 2.5 carats of flawed diamonds, valued at £200.
Comment: When diamonds form deep in the earth, they do so under tremendous amounts of pressure and at very high temperatures. If solidification (crystallisation) of the diamond occurs in an area where Boron is present, this will cause the diamond to fluoresce.

Jewellers are well aware of the fluorescent properties of diamonds and use ultraviolet lights to screen stones. The property of fluorescence is something that can either enhance or diminish the value of the diamond, depending upon the visually qualities desired from the stone and the fashions of the day. In the past, the blue-white was the most desired and dazzling diamond. In recent years however, its brighter-than-bright quality was attributed to the fluorescence of the stone and the fortunes of the blue-white fell. The presence of fluorescence is not all bad news though as many jewellers realise it gives that little extra sparkle to a stone that may contain a number of impurities that effect its ability to shine.

B.9 Zebrafish and GFP

Contents: . Two 10ml vials, one containing a Zebrafish in formaldehyde and the other containing dried concentrated green fluorescent protein.
Comment: Green fluorescent protein (GFP) is a naturally accruing protein in the bioluminescent jellyfish, *Aequorea victoria*. In recent years GFP has become somewhat of a celebrity within the world of genetic engineering and biological research for it has been extracted from this jellyfish and engineered into the cells of other animals. High profile images of glowing rabbits, pigs and mice, bring the fluorescent reality of GFP into the headlines and overshadow the subtleties at work. At first glance, this Zebrafish appears unremarkable; it is only the vial of concentrated

GFP that is displayed next to it that hints at the wonders of the fish's genetic make-up. One cannot see the fluorescence of this fish is because it is designed to be viewed under a microscope, thus the levels of fluorescence are not required to be visible with the naked eye. The reason this fish has been engineered to express GFP is so that the growth and development of embryo cells can be made visible, under ultraviolet light, to biologists. This allows the development of an understanding of how cells form, divide and mutate, bringing us closer to an understanding foetal deformities and genetic anomalies.

Installation

The Essence of Fluorescence was installed alongside a number of other responses to the science of Flavin's work within the experimental resource space. This space, especially entitled AfterImage, was located within the main gallery on the second floor and visitors were free to walk through it as they made their way around the show. The layout of works within the AfterImage space is shown in figure 9.7.

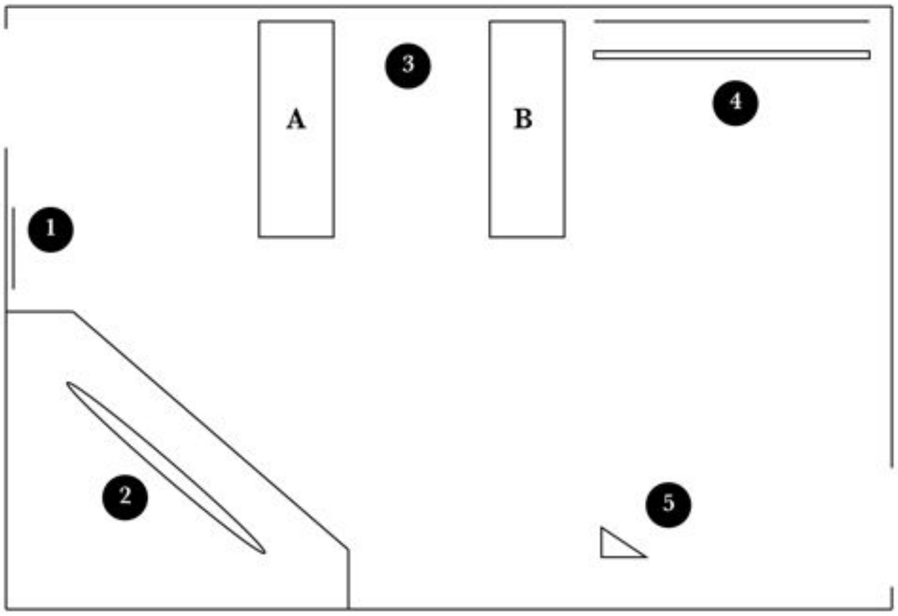

Figure 9.7: Map of the AfterImage room depicting the layout of the following contents. 1; Silent film projection depicting the history of the electric light. 2; A Wimshurst machine. 3; The Essence of Fluorescence. 4; An optical illusion involving shadows. 5; A large glass prism splitting white light into its constituent parts.

The Essence of Fluorescence cabinets were purposely aligned so that they faced each other and visitors were required to enter the space between the cabinets in order to regard their contents. A black roof panel was attached to the cabinets and the final effect and configuration can be viewed in figure 9.8. The reason for this alignment was primarily practical. Arranging the cabinets thus provided a suitably dark environment within which to view the contents of the cabinets. In any other configuration extraneous light from both the shadows illusion (number 4 on figure 9.7) and Flavin's works in the neighbouring room shone onto the windows of the cabinets, obscuring the subtle light emitted by the objects within. A dark environment was paramount for the visual success of *The Essence of Fluorescence*, enabling the control of fluorescent effects, the revelation of visual transformations and the perception of material behaviours.

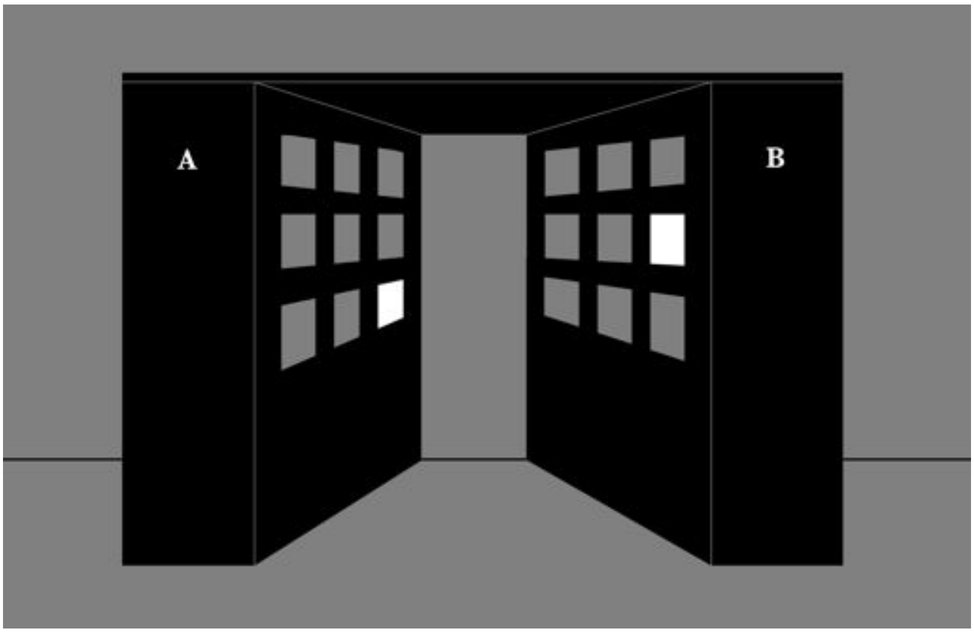

Figure 9.8: A graphical representation of the alignment of cabinets A and B of *The Essence of Fluorescence* installation. The additional roof panel is also shown.

9.2.2 Event

The Essence of Fluorescence, as part of *Dan Flavin: A Retrospective*,[2] was open to the public from the 9th of January to the 2nd of April, 2006. Within the AfterImage room, depicted in figure 9.9, double sided A4 handout sheets were freely available for visitors to take. The sheet gave an overview of the contents of the AfterImage space and with regard to *The Essence of Fluorescence*, it provided a graphical key to the cabinet contents as well as the Materials Library website address at which further information on the project was located.[3] A copy of the handout

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[2] The website that the Hayward gallery produced to accompany the Flavin show can be accessed here; http://www.southbankcentre.co.uk/flavin/retrospective.htm

[3] Documentation of this information can be found at;

can be found in Appendix B of this thesis. Over the course of the exhibition 40,000 hand-outs were taken by members of the pubic who visited the show.[4]

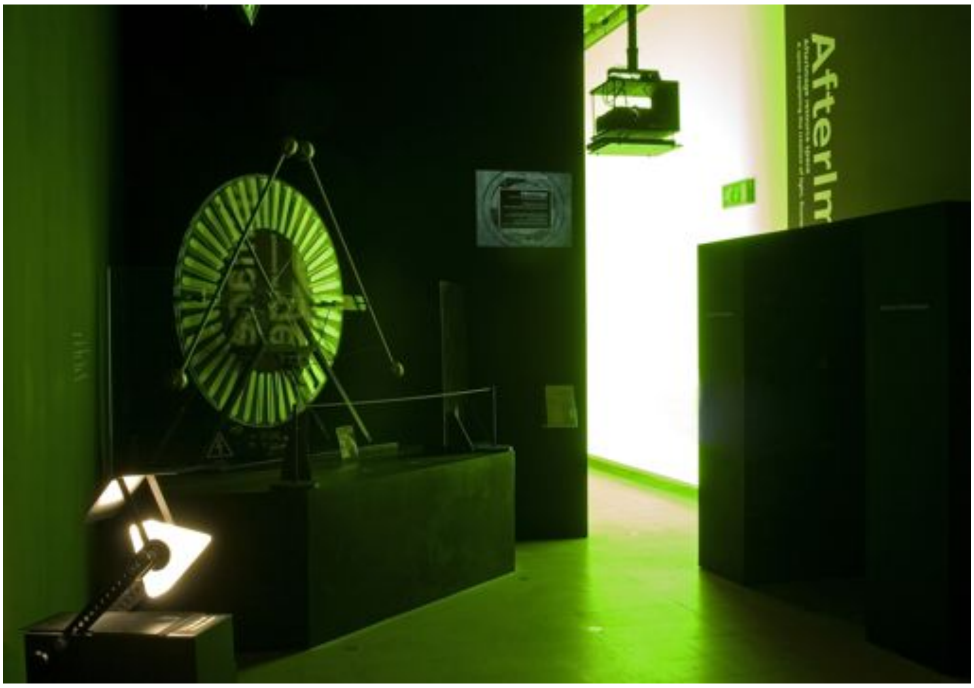

Figure 9.9: The AfterImage space. The green light was bleeding into the space from the adjacent room in which the green side of Dan Flavin's work *untitled (to Jan and Ron Greenberg)*, (1972 - 73) was displayed. This photograph was taken from the bottom right doorway shown in figure 9.7.

The contents of the Materials Library's Essence of Fluorescence web page was designed to reference the cabinets with the use of the nine windowed grid and black surround. On passing the cursor over any one of the windows the text within it flashed a green colour, alluding to the changing lighting conditions and fluorescent effects experienced within the instillation. When any one window was clicked on, an image of the contents of that window appeared below and was accompanied by a brief text detailing something of the observed phenomena and story of the object. A screen shot of *The Essence of Fluorescence* page can be seen in figure 9.10. The uranium glass fruit bowl in window A.2 has been highlighted and the image of the object appeared along with an accompanying text.

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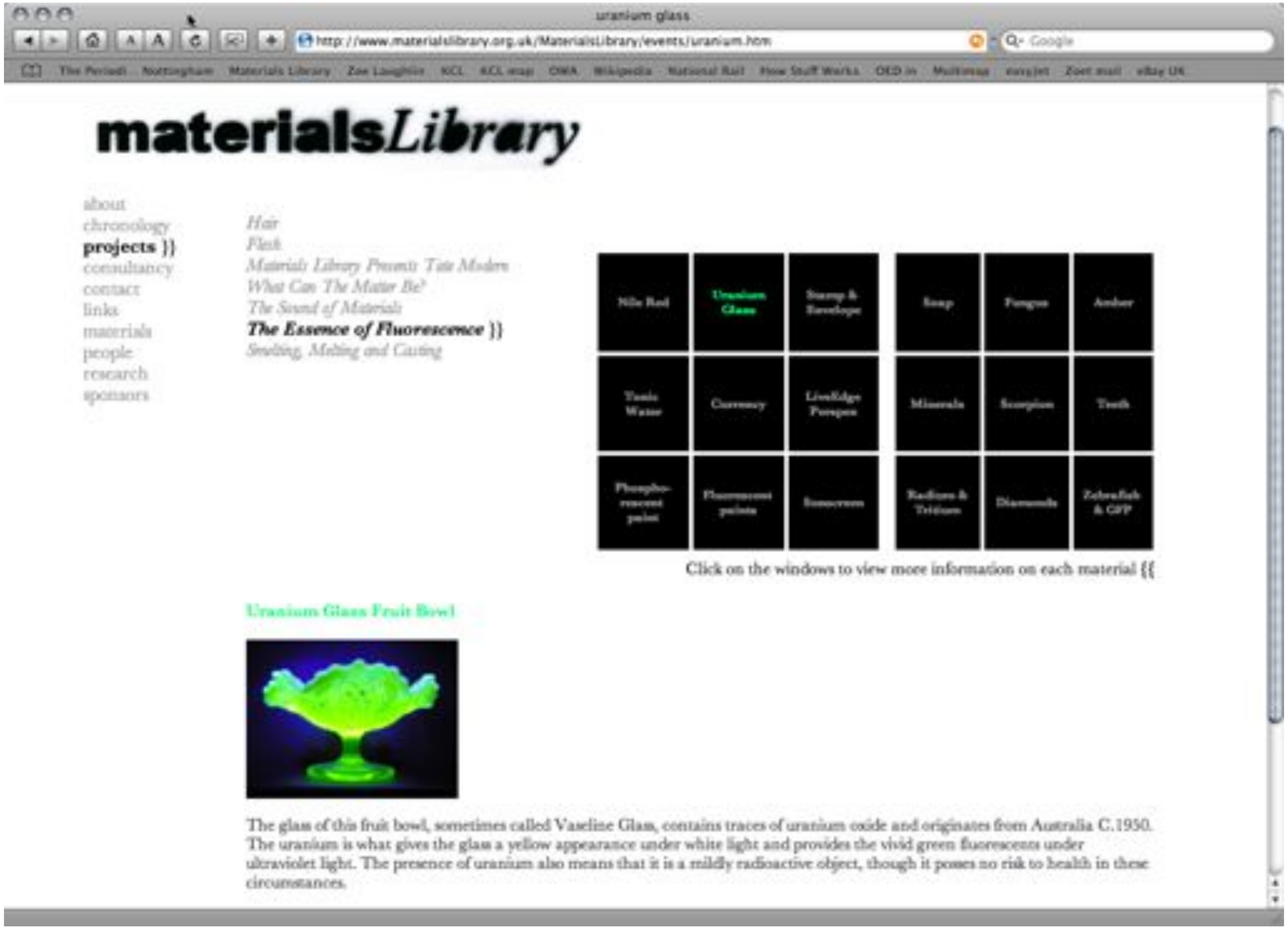
http://www.materialslibrary.org.uk/MaterialsLibrary/events/essence.htm

[4] The figure of 40,000 was supplied by the Hayward Gallery's Educational Resources Team in April 2006.



Click on the windows to view more information on each material {{

The glass of this fruit bowl, sometimes called Vaseline Glass, contains traces of uranium oxide and originates from Australia C.1950. The uranium is what gives the glass a yellow appearance under white light and provides the vivid green fluorescents under ultraviolet light. The presence of uranium also means that it is a mildly radioactive object, though it poses no risk to health in these circumstances.

Figure 9.10: The uranium glass fruit bowl selected on *The Essence of Fluorescence* web page, materialslibrary.org.uk

During the course of the exhibition a series of gallery talks were given by the author and the other AfterImage curators under the banner of "Saturday Science Séances." Each session took place within the AfterImage room and ran from 13:00 to 15:00hr on Saturday the 21^{st} of January, the 18^{th} of February, the 25^{th} of March, and the 1^{st} of April 2006. The talks were structured so that each speaker would present their work to the crowd for about fifteen minutes and then take specific questions from the floor. Once each person had presented, we broke off into more informal groupings around our specific exhibits. The general purpose of the Séances was to introduce the projects and the concepts we were trying to communicate and then be on hand to expand people's understanding of the work. Questions range from specific enquiries into items on display to general questions on the phenomena of fluorescence. In talking about *The Essence of Fluorescence* I used a number of visual aides to explain the phenomena in relation to how a fluorescent tube works. These ranged from two hand held ultraviolet lights of differing wavelengths to some invisible fluorescent makeup and a synthetic ruby.

Observations

The following scenarios are transcripts of specific instances of visitor interactions observed and documented by the author within *The Essence of Fluorescence* installation. This ethnographic field work was carried out repeatedly on Monday the 13^{th}, 20^{th} and 27^{th} of February 2006 between 15:00 and 16:00hr. Each day the author situated herself at the entrance of the cabinets with a tape recorder and notebook for thirty minutes in order to observe visitors at close range before retreating to the other side of the room for a further thirty minutes to make more general statistical observations. Visitors were not filmed (as would be done by ethnographic filed workers specialising in gallery observation (Heath and Lehn, 2004)) as the lighting level was too low and the Hayward Gallery were not in favour of this form of documentation for both ethical and copyright reasons. Interviews were not conducted with visitors for it was the observed behaviours and natural interactions of visitors that were of interest, rather than a formal qualitative assessment of their perceived experience. The following dialogues were recorded in the period of observation at close quarters and are transcribed word for word. The accompanying notes on actions and other observations [signified in square parentheses] were made in real time in the form of field notes –the primary tool for the ethnographer to record their observations (Burgess, 1984).

Scenario 1:

[Mother (M) and Child (C) estimated age 3. They stand at the entrance of the cabinets.]

C: "What's this Mum?"

M: “Wait your turn. You can go in in a minute.” [they wait about 15 seconds] M: “We’ll come back.”

[M and C return after about three minutes]

M: “It’s very busy.”

[She turns to two women also standing in the outer area of the cabinets]

M: “Are you waiting to go in?”

[The two women go in]

M: “It’s these ladies turn and when they come out it will be our turn.”

M asks me(Z): “Are you waiting to go in?”

Z: “No, I’m just observing”

M: “Do you know anything about these then?”

Z: “Yes” [I give a brief explanation of what the cabinets are about.]

[M and C go in. She lifts him up to see lit window A2. He reaches out and slaps his hand on the glass window]

M: “Hey what have we got here Zackie?”

C: “Money”

M: “Yes Zackie. Look how the 20 comes out.”

[M continues to hold child up until the lower rows are illuminated. Then she physically prompts him by crouching down with him between her legs, holding his torso and pointing within the line of his sight, occasionally touching glass. They are joined in the space by a man in a suit. M and C turn round to look at cabinet B. She picks him up and holds him to window B3.]

M: “Oh look Zackie, what’s that?”

C: “Stone.”

M: ”Looks like amber. Oh amber turns green under the special light. Look Zackie, teeth. Do you remember when your tooth came out?”

[C touches every on window on the glass and when the lower windows are illuminated and he is standing on the floor, he tries to press the bolts that keep the front of the cabinet in place as if the were buttons.]

M to Z: “It’s his favourite thing of the whole exhibition.”

[They leave having seen every object in the two cabinets.]

Scenario 2:

[A couple are inside.]

Him: “Do you think its a real £20 note?”

[He talks and directs her gaze by pointing, she looks at the objects in turn and says nothing.]

Him: “Is that milk or sodium? Sodium. Has to be.”

[The Wimshurst starts up. He watches it for the whole time it spins. She glances at the machine but returns to the windows.]

Scenario 3:

[A male is in the cabinet space on his own. Estimate age at 37 years. He stands against the back wall inside the cabinet space and looks left and right to view cabinets A and B simultaneously. He is joined be a female of similar age.]

Him: “Look, objects under UV. I’ve got a UV light at home. It would be good to go round and see what fluoresces.”

Her: “Look! Teeth.”

Him: “Yes. I know about that one. It’s calcium in the water.”

[They drift out.]

Scenario 4:

[Two females enter. F1 and F2, both art student types, mid 20s.]

F1: “Ooow” [makes a sound like a firework appreciation noise]

F2: “What’s going on here?” [glances around at a number of windows]

F1: “Hey look... [she points to nile red in A1.] Wicked! Which is coming on next? I guess this one. [She points quickly] Oh no, this one.”

[People in the outer area lean in]

F1: [Turns her attention to window A5.] “Its real. I’ll smash it. [She does a thumping hand action onto the glass] “Oh look how the 20 comes out.” [Traces area on the glass with forefinger.]

[The two women move to leave the cabinet inner zone]

F1: “I think we’ve seen them all” [the light changes from white light to UV in window A8] “Oh no, we’ve not.” [Stops and looks at the Bristol paint swatch] “Wow!”

[The Wimshurst comes on and both women give it their attention. Once the machine has stopped spinning they both leave the cabinet space.]

Statistical Observations

Made during a 30 minute period of observation on Monday 20th February 2009.

Group sizes:

One person: 6 (6 people)

Two people: 7 (14 people)

Three people: 5 (15 people)
Four people: 1 (4 people)
Five or more people: 0

Quantitative Data:
Number of people who entered the cabinet area: 39
Number of people who peered in but did not fully enter the cabinet space: 13
Number of groups (including single visitor groups) that stay over one minute: 8
Number of people who touch the glass 1-2 times: 10
Number of people who touch the glass repeatedly (3 or more times): 7
Number of people estimated to be under ten years of age: 4
Number of people estimated to be between 11 and 15 years of age: 3
Number of people who refer to the sheet with the cabinet contents key on it: 1

9.2.3 Aftermath

After the conclusion of the exhibition, but before *The Essence of Fluorescence* cabinets had been moved, I undertook the retrieval of forensic information that pertained to the touching of the cabinet's glass windows, in an attempt to gather further data on visitors' interactions with the installation.

From a specialist supplier[5] I procured a pot of non-magnetic latent fingerprint powder in silver/grey, a Zephyr fibreglass bristled brush used for dusting the powder onto surfaces, and black lifting gels (15 x 21cm) that are used to capture and preserve the powdered print. Lightly dipping the ends of the brush into the tub of powder, I applied a thin layer of the powder onto the panes of glass using a gentle circular motion. Once each window had been fully dusted I selected an area on each pane from which I would lift the powder using a gel. The dimensions of the gels was less than that of the glass windows which prohibited the retrieval of the entire area of prints. Never the less, the area of the gel was sufficient to gain representation from all the windows on the nature of the prints found. Figure 9.11 depicts the alignment of each gel in respect of the window on which it used and shows the variation in lift orientations and position within the window. The typical appearance of a gel containing lifted prints can be seen in figure 9.12.

More specifically, figure 9.12 shows the lifts retrieved from window 5 of cabinet A, behind which the £20 note was housed, and window 1 from cabinet B that displayed the bar of soap.

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[5] Lightening Powder Company Inc. USA. www.redwop.com

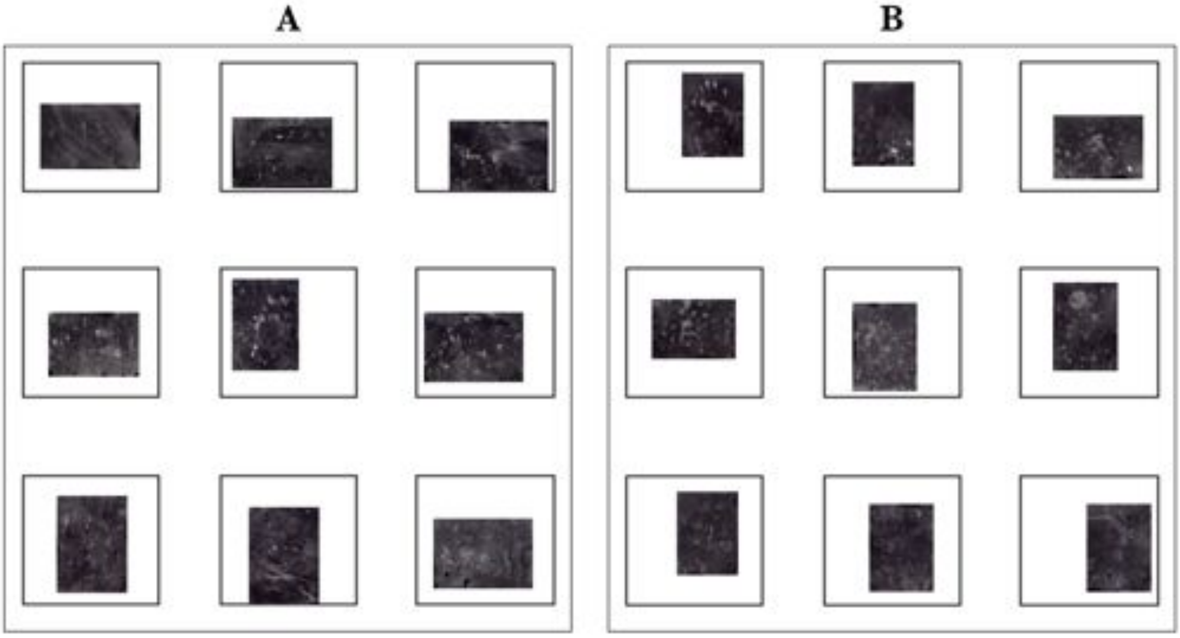

Figure 9.11: The finger print gel lifts aligned and orientated on the windows from which the lift was taken.

Both lifts show circular and oval shaped finger prints left on the windows. Such shapes are made by the ends of fingers as the result of visitors pointing at the item behind the glass. The gesture of pointing may be done with the intent of drawing the attention of another to the that which resided behind the glass, as an action that accompanies a verbal cue like "look at this one". It is also possible that some prints are made as the result of testing to see if there is indeed glass in front of the objects and that they are thus prohibited from handling it.

A number of other visitor actions may also be deduced from specific marks left on window B1, as seen on the right of figure 9.12. A faint '*Z*' shaped smear is visible on the centre right of the lift. One may deduce from examination of this mark that it is the result of a single finger pointing and then moving across the surface of the glass in an attempt to further animate and draw attention to the pointing gesture, signalling interest in the item behind the glass. There is also a partial hand print on the upper centre of the lift. As is shown in figure 9.11, the gel from window B1 was taken in a portrait orientation from the top right portion of the window that resides at the top of the cabinet –approximately 1m 70cm from the ground. The length of the index finger of the palm (approximately 4cm) suggest that this is the hand print of a young child who would have clearly been too short to reach this height. As a result one can imagine that the child was lifted up by an accompanying adult to view inside the window. In this position the child could then reached out in an attempt to touch the object or simply slap their hand

Figure 9.12: Gel lifts from window 5 of cabinet A (left) and window 1 of cabinet B (right) showing visitors finger prints.

upon the glass in acknowledgement of its content –an action represented in figure 9.13.

The forensic evidence of the gel lifts proves that touching of the glass happened but also reveals something of the nature of the touch, gestures and interactions that occurred in order to cause the marks. Figure 9.13 depicts a number of poses observed during the formal period of observation at The Essence of Fluorescence installation. The central and right hand side poses can also be deduced from the examination of the finger prints left on the glass.

Once *The Essence of Fluorescence* had been un-installed, the items within the cabinets became a formal part of the Materials Library collection. In this way, the act of curating and creating *The Essence of Fluorescence* had a direct impact upon the contents of the Materials Library. Whilst the uranium glass fruit bowl and the live edge perspex pencils were already items within the Materials Library collection, a large number of new materials were added to the Library as a result of research and the desire to collect things that represented the diverse nature of fluorescent materials. For example, the green fluorescent protein, the scorpion and the diamonds were all acquired especially for the show but are now housed in the Materials Library.

In the 30 minute period of statistical observation, 39 visitors entered *The Essence of Fluorescence* installation; of these, 17 people (44%) touched the glass. Despite weekly cleans by

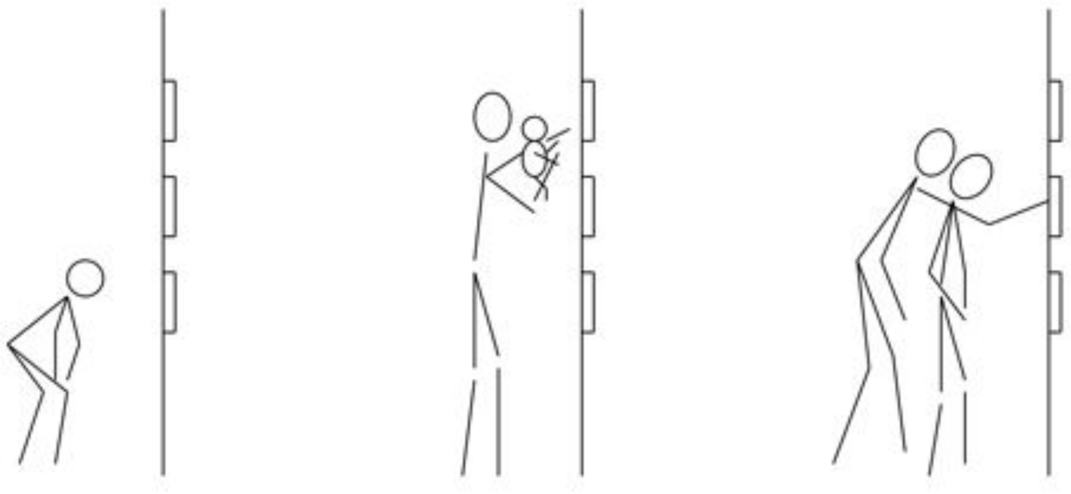

Figure 9.13: Three common poses of visitors viewing The Essence of Fluorescence cabinets. From left to right: Singular visitor crouching to see the lower window; Parent holding child up to view a high window; Couple viewing windows together with one pointing.

gallery staff, the glass of the cabinets was found to have multiple print marks upon it that are clear evidence of the visitor's desire to touch. The use of this forensic method provides evidence that enables the extrapolation of visitor behaviours and possible scenarios that were prompted by the work. Even within the context of a gallery exhibition where the prohibition of touching artworks is standard practice, the desire to touch, reach out and gesticulate towards an object is readily demonstrated. The glass windows of *The Essence of Fluorescence* cabinets obviously prohibit visitors from any direct physical encounter with the artefact inside but the glass is not only preventative but can also be seen as an enabler touch. Expressions of desires to touch the objects can be acted out on the pane of glass, safe in the knowledge that the artefact will not be damaged. Force can be used, as in the case of F1 in Scenario 4, or the gaze of a companion directed and held, as seen in Scenario 2.

9.3 Materials Library Presents... Tate Modern

In November 2006, Materials Library staged "*Materials Library Presents...* Tate Modern", a series of four performative investigations, highlighting the art, science and materiality behind some of the works of art in Tate Modern's rehung permanent collection. Each of the events took place within the gallery space of Tate Modern, focusing in turn on the four newly hung collection areas; Material Gestures, Poetry and Dream, States of Flux and Idea and Object.

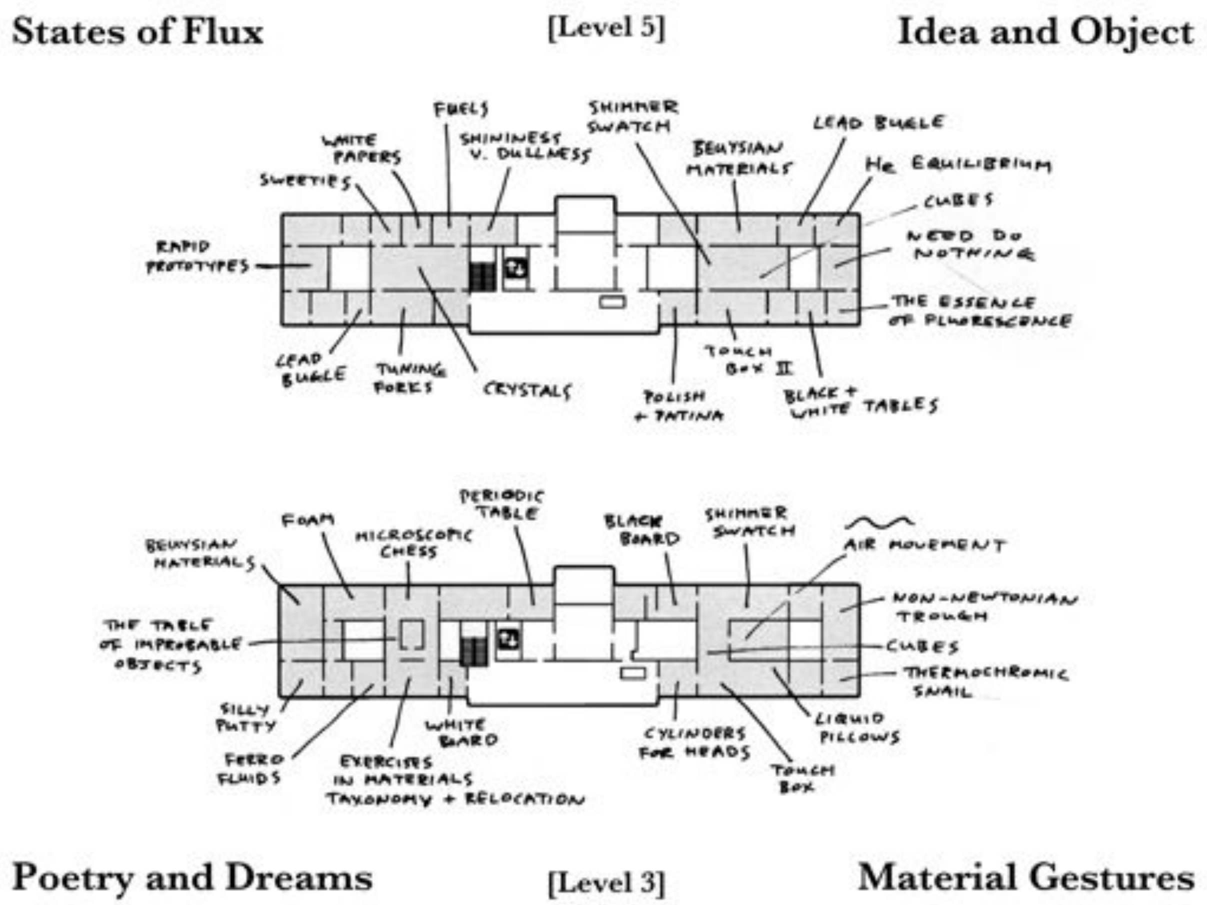

Figure 9.14: Graphic floor plan of the four Tate Modern gallery spaces that house the permanent collection displays. This image was used at the front of the booklet that was made as an accompaniment to the event.

9.3.1 Set-Up

The approach was to use materials as a tactile language with which to explore the scientific, cultural, material and sensual aspects of the art on display within Tate Modern's permanent collection. Materials Conjectures were devised and created to act as physical interfaces with materials, facilitate conversations and allow haptic, olfactory and auditory engagement with matter. The standard gallery mantra of "please do not touch" was abandoned with central premise of each Conjecture being "please do touch". The decision to put such emphasis on the visitor being allowed to touch was made in response to the formal denial of touch seen in *The Essence of Fluorescence* instillation. Although touching the exhibited items was denied by the glass windows in that case, the observed behaviours of visitors and the finger print evidence revealed that the act of touching played a big part in the way in which visitors interacted with the work. The desire to touch within a gallery context was clearly evident and the *Materials*

Library Presents commission afforded the opportunity to celebrate, enable and experiment with touch, as a method of interaction with work, within a gallery context.

In total, forty Materials Conjectures were conceived and created (ten for each evening). Figure 9.14 locates each of the Materials Conjectures on the gallery plan of Tate Modern, demonstrating the spread of activities and the scale of the project undertaken. As well as drawing on the pre-existing resources of the Materials Library, new objects were collected, commissioned, made and donated to form these Conjectures.

Each Materials Conjecture was located beside or in front of a specific work of art, from which it drew inspiration or to which it spoke sensorially, conceptually or materially. To signify the difference between the artworks within the Tate collection that could not be touched and the temporarily installed Material Conjectures that could be touched, each of the Conjectures was manned by a Materials Conjecturer, visually framed and specially demarcated by the use of rectangular tables, covered with black table cloths, upon which each Conjecture was presented (as represented in figure 9.15). The semiotic nod to theatrical devices of magic and performance were intended to enforce the live, active component to the Conjectures, in contrast to the static presentation of the art.

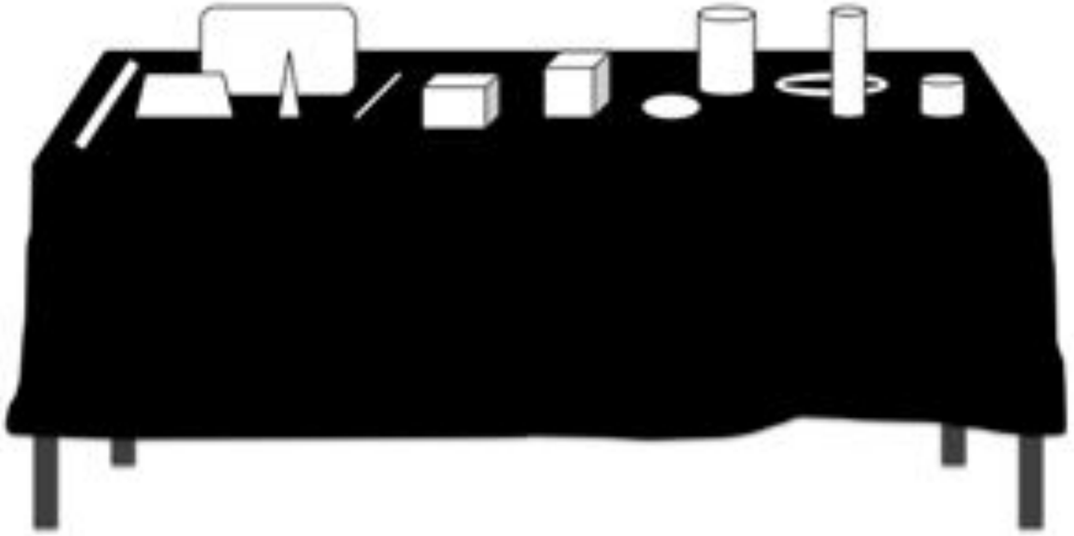

Figure 9.15: A representation of a typical Conjecture table with a number of forms upon it. The table is covered with a black table cloth that acted as a Conjecture motif.

The following outlines each of the Conjectures presented in each of the gallery spaces and gives a brief description of each. In every case, the Conjectures were devised, curated and created by the Materials Library with the author taking the lead roll.

Material Gestures Conjectures

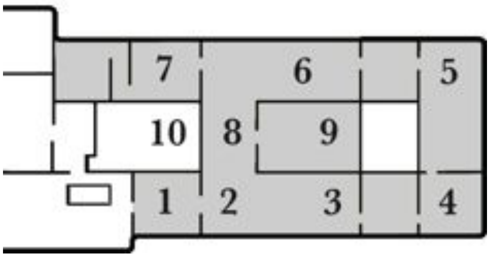

Figure 9.16: Floor plan of the Material Gestures gallery of Tate Modern, Level 3, East. The numbers indicate the location of each Conjecture.

1. Cylinders for Heads

Cylinders for heads was conceived in relation to Anish Kapoor's fibreglass and lacquer sculpture *Ishis Light* (2003). Standing over three meters in height, *Ishis Light* is a oblate spheroid (egg) shape with a highly reflective internal surface. Visitors to Tate Modern used to be able to enter into the sculpture's immersive space and experience the visual and acoustic effects generated by the relationship between the form and the material from which it is made. This has since been prohibited and the entrance to the internal chamber of the sculpture blocked by a guide rope as a result of the continual touching of the lacquered surface by those inside the work. In order to bring back something of this experience to the work and investigate the relationship between form, material and experiential effect, an array of immersive vessels were provided for the audience to experience alongside Kapoor's work. These ranged from an anodised aluminium bucket, a black plastic bucket, and a terracotta flowerpot, to a specially constructed cylindrical chamber of plywood and brass sheet, into which audience members could walk. The array of finishes and materials used to construct the vessels highlights the effect of material selection and surface finish on the visual and acoustic properties of objects.

2. Touch Box

The gallery's blurb that accompanied Jean Dubuffet's painting *The Exemplary Life of the Soil (Texturology LXIII)* (1958) states that; "Dubuffet invented various techniques to portray soil in a series of paintings called Texturologies" (Tate Modern, 2006) –a highly evocative term for what is an extraordinarily compelling effect. In looking at *The Exemplary Life of the Soil*, one is almost swept into a synesthetic experience where, by just looking at the painting, one feels as if one is running a hand over it. Very quickly a compulsion to touch the picture is felt as the desire to check if the visual data will match the haptic. With this in mind, we made a blind touch-box with five apertures (as seen in figure 9.17) that was placed directly in front of the painting. Behind each opening, a different material sensation awaited, providing the opportunity for the exploration and juxtaposition of visual and haptic information. The five materials chosen to reside within the touch-box were soil, tiny glass beads, silly putty, feathers and gravel.

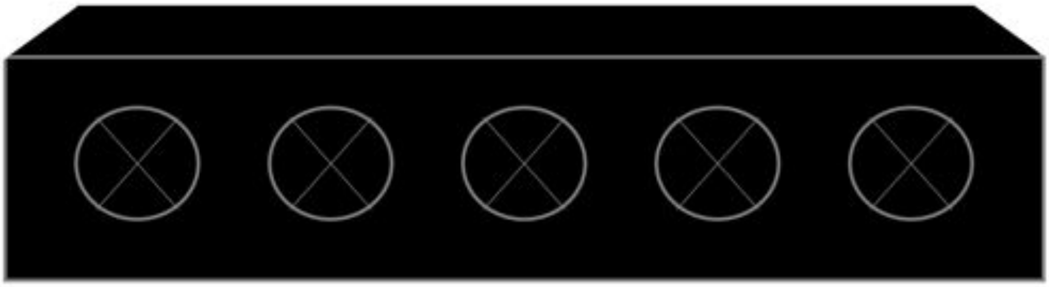

Figure 9.17: The Touch Box Conjecture. A wooden construction, painted matte exhibition grade black with 5 internal compartments, accessible through the circular apertures. Each aperture was covered with 5mm rubber scored with an ‘X’ to enable arms to be pushed through whilst still masking the contents.

3. Liquid Pillows

This conjecture consisted of thirty pouches of various sizes filled with sodium acetate –a liquid that spontaneously solidifies and increases in temperature when provoked. In order to return each pillow of sodium acetate to it’s liquid state, a saucepan, hot plate and a bucket of ice water was provided within which the pouches could be first boiled, enabling the sodium acetate crystals to melt and then cooled, ready for reuse. The liquid pouches were placed in front of Jean Dubuffet’s painting *The Tree of Fluids* (1950), a work that used paint to investigate the “patterns and textures” that Dubuffet saw in “the world of fluids” and which he represented with paint (Tate Modern, 2006).

4. Thermochromic Snail

This Conjecture featured a full size reconstruction of Henri Matisse’s *The Snail* (c.1953, 2864 x 2870 mm) in thermochromic papers, arranged on the floor of the gallery space in front of Matisse’s work. Each of the papers was cut to size and painted with thermochromic pigments that corresponded to the colours used in the original. The thermochromic pigments had been specified to change colour (from what ever their starting colour was, to white) at $20°C$. During the course of the Conjecture activity, visitors were invited to take their shoes off and then walk upon the arrangement of papers, thus changing the colours of the paper with the heat from their feet, leaving temporary footprints as a visible trace of the participant's interaction.

5. Non-Newtonian Trough

The Non-Newtonian Trough was installed in the room where Gary Hume's 2389 x 3846 mm painting *Incubus* (1991) hung. The painting is entirely pink and uses gloss alkyd house paint, giving the surface of the painting a wet-look finish. The Non-newtonian Trough Conjecture, represented in figure 9.18 was a purposed built 750 x 450 x 450 mm glove box containing a non-newtonian fluid to the depth of 60 mm. A non-Newtonian fluid is a fluid that changes viscosity when a force is applied to it. In such fluids, viscosity can either decrease, as in the case of thixotropic non-Newtonian materials like ketchup or toothpaste, or increase, as in the case of dilatant non-Newtonian fluids like custard or silly putty. If one slowly moves one's hand through such a dilatant fluid it will behave like water but if one applies any rapid movements or hits the surface of the liquid, it behaves like a solid due to its shear thickening properties. Inside the non-Newtoninan Trough we created a dilatant fluid by mixing corn flower and water to create an opaque white starch suspension. To complete the conjecture we dyed the liquid pink using red food colouring in order to mimic to colour of *Incubus* and then placed a hammer inside the box for people to bash the liquid with.

6. Shimmer Swatch

For this Conjecture we created a giant shimmering swatch of the shiniest aluminium in the world in all the 'A' sizes ranging from the credit-card sized A7 (74mm x 105mm), right up to the human sized A0 (841mm x 1189mm). Participants were able to explore the effects of scale on the perception of materials and the properties that are affected by altering the size of samples. For example, not only were the optical effects of the aluminium altered as the sample size increases, but so too did the acoustic properties of the material. We also provided a range of torches for people to use in conjunction with the aluminium in order to investigate the quality of the reflected light. This Conjecture was located beside Claud Monet's large scale work *Water-Lilies* (1916), 2007 x 4267 mm.

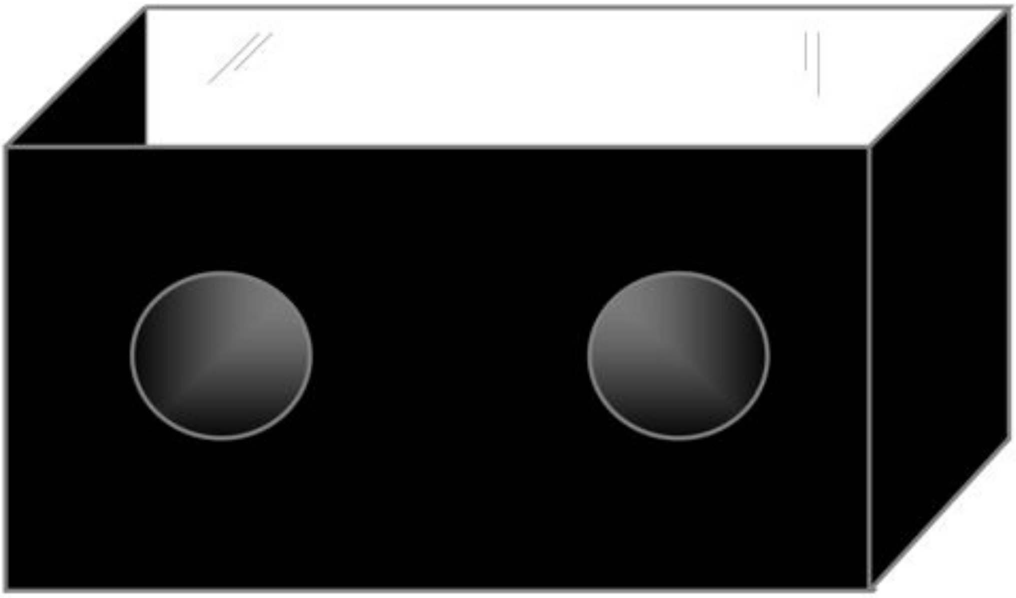

Figure 9.18: Glove box made for the Non-Newtonian Trough Conjecture. The front face (750 w. x 450 h. mm) has two holes cut into it with thick black rubber gloves sealed to the circumference so that users can reach into the box and manipulate the material within, whilst preventing any of this material leaking out. The majority of the construction is wood painted with waterproof black paint, though the top and back wall of the trough is made from acrylic, enabling easy viewing of the contents of the box.

7. Blackboard

This conjecture consisted of a large blackboard on an easel, painted with 12 different types, and thus shades, of black paint. The different blacks were: Magnetic Blackboard Paint, Matt Super Black, Barbecue Paint, One Coat Blackboard Paint, Carbon Black Acrylic, Bone Black Acrylic, One Coat Matt Black, 1 ml Total Black[6] Black Nail Varnish, Roof Sealant, Matt Black Enamel Paint, and Doorstep Paint. The custom painted blackboard was then placed inside the Tacita Dean room containing the work *The Roaring Forties: Seven Boards in Seven Days* (1997). Sticks of chalk were provided along side the blackboard for visitors to draw marks across the surfaces and experience the different paints enabling and disabling the style of the lines that could be drawn, as well as producing a variety of audible effects.

8. Materials Cubes

This conjecture consisted of sixty cubes, each measuring 40 x 40 x 40 mm, made from a range of different materials; from chocolate and clay to tungsten, aluminium, balsa and glass. The

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[6] *1 ml* Total Black was a paint made special for the event by *Siecle Colours*, paints. The paint was a highly pigmented solution made from a 1 millilitre injection of every pigment they used to make their entire paint range.

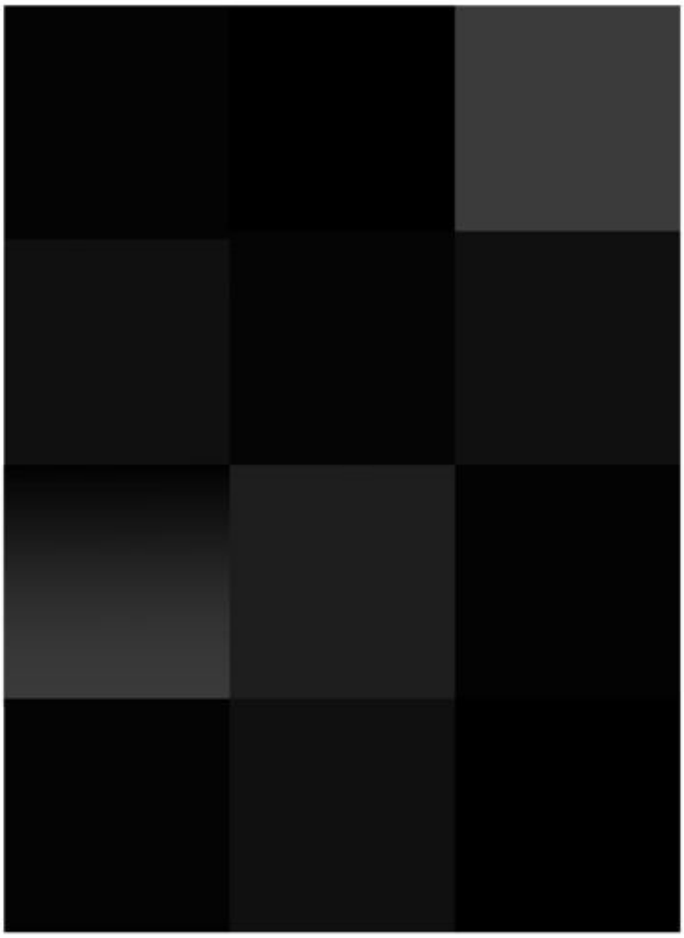

Figure 9.19: A representation of the Blackboard Conjecture painted with 12 different types of black paint, each in a square measuring 300 x 300 mm.

array of cubes was presented alongside Lucio Fontana's bronze sculpture *Nature* (1959–60). As is the case with the majority of exhibited art works, a statement on the dimensions of the work is presented on the label adjacent to the piece. This label states that the work is 610 x 730 mm but no indication of the weight of the work is given. To this end, the array of cubes was designed to go some way towards providing an understanding of the relationship of material to the mass of an object. The audience were encouraged to pick up, handle and examine the cubes in order to increase their knowledge of the physical presence of the materials and form relative appreciation of the differing densities of materials.

9. Air Movement

This conjecture took place within Material Gestures' Rothko Room that contained a series of seven large scale paintings by Mark Rothko entitled *Black on Maroon / Red on Maroon* (1959–

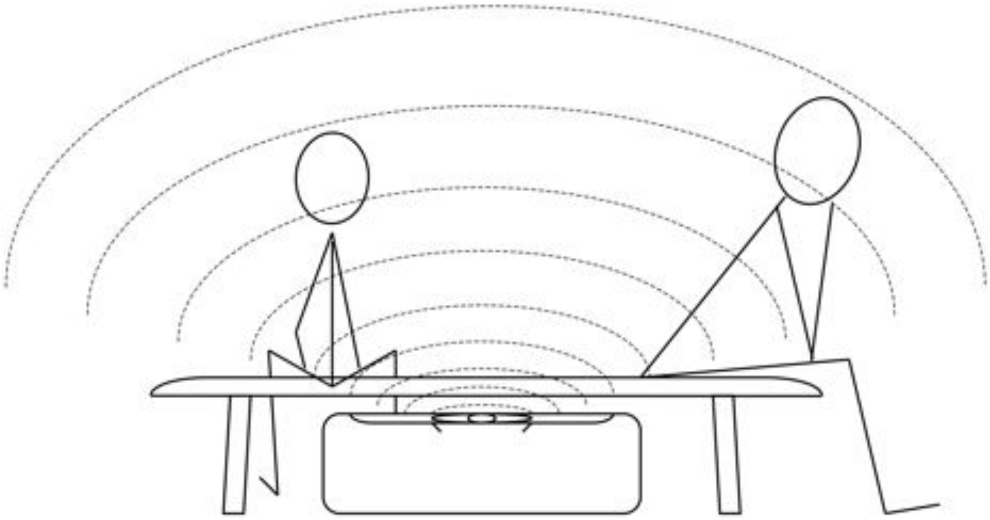

Figure 9.20: A graphic depiction of one of the benches within the Rothko room with a bass sub-woofer speaker underneath it and two people sitting upon it. The vibrations produced can be felt through the wood of the bench and the air movement within the room.

60). The conjecture consisted of two bass sub-woofer speakers, one placed under each of the benches within the Rothko room, playing a looped sound piece composed especially for the Conjecture (see figure 9.20). The piece lasted for five minutes and was simply a sweeping tone playing at a high volume that went from 0Hz to 40Hz over the course of the five minutes. Sounds below 20Hz are inaudible to even the keenest human ear but can be felt as vibration through objects and in the matter of our bodies. The resultant soundscape created was thus only audible for half the time it was playing but could be felt much before it could be heard. The audience were encouraged to enter the space and experiencing the barely audible but physically detectable movement of the air around them.

10. Stethoscope

For the duration of the evening five stethoscopes were available for people to take around the gallery and listen to any conjectures, as well as any other surface they wished to place the stethoscope against. For the majority of the time this was against each other, drawing attention to our material presence.

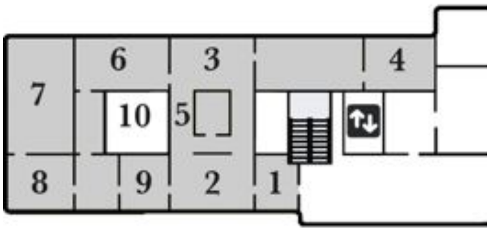

Figure 9.21: Floor plan of the Poetry and Dream gallery of Tate Modern, Level 3, West. The numbers indicate the location of each Conjecture.

Poetry and Dream Conjectures

1.Whiteboard

This Conjecture was the whiteboard version of the Blackboard Conjecture in Material Gestures. It consisted of a Whiteboard painted with following 12 different types and shades of white paint; Golden™Acrylic Titanium White, fast dry white gloss enamel, Wildfire™ultraviolet fluorescent paint, the original whiteboard surface, Plasti-Kote™super matte white, Solo self-undercoating gloss non-drip pure brilliant white, Golden acrylic zinc white, Weathershield™exterior gloss with mould resistant film, weatherproof pure brilliant white, quick drying white correction fluid (Tipp-Ex™), Tri Art™iridescent high viscosity pearl white, white nail varnish, and fast dry flat white enamel. The custom painted whiteboard was then placed besides Jannis Kounellis's installation (1979) that used charcoal, paper, arrows and stuffed birds as its materials. Sticks of charcoal were provided alongside the whiteboard so that visitors could draw marks across the surfaces and experience the contrasting textures of the paints and how this affects the nature of the lines that can be drawn. An ultraviolet light was also provided for people to shine onto the whites and compare the differing fluorescent effect.

2. Foams

René Magritte's painting *The Reckless Sleeper* (1928) pictures a surface into which a number of objects are recessed. To accompany this painting a conjecture was created that explored foams and the way in which items can be pressed into them. Some of the materials on the table included; a piece of Tempur™Mattress foam (used by NASA in their shuttles), a piece of memory foam from VitaFoam™, polyurethane foam, self-skinning foam, rigid foam, foam pan scourer, biodegradable foam, pink foam sphere, indoor foam golf ball, packing foam, natural sponge, synthetic sponge, Angel Delight™, and squirty cream.

3. Microscopic Chess

This conjecture was located in the Beyond Surrealism room of the Poetry and Dreams gallery and consisted of a microscopic chess set made by acid etching and photolithography, a ProScope™microscope and two sets of fine gauge tweezers. The idea was to make a chess set that could not be seen by the naked eye and in order to use it, players were required to view the board through a microscope and move the pieces with tweezers. Although in the final chess set, the pieces were visible to the naked eye, the form of the piece was not. In other words, the difference between a Knight, Pawn, Bishop, or Queen could only be determined through the microscope.

4. Periodic Table

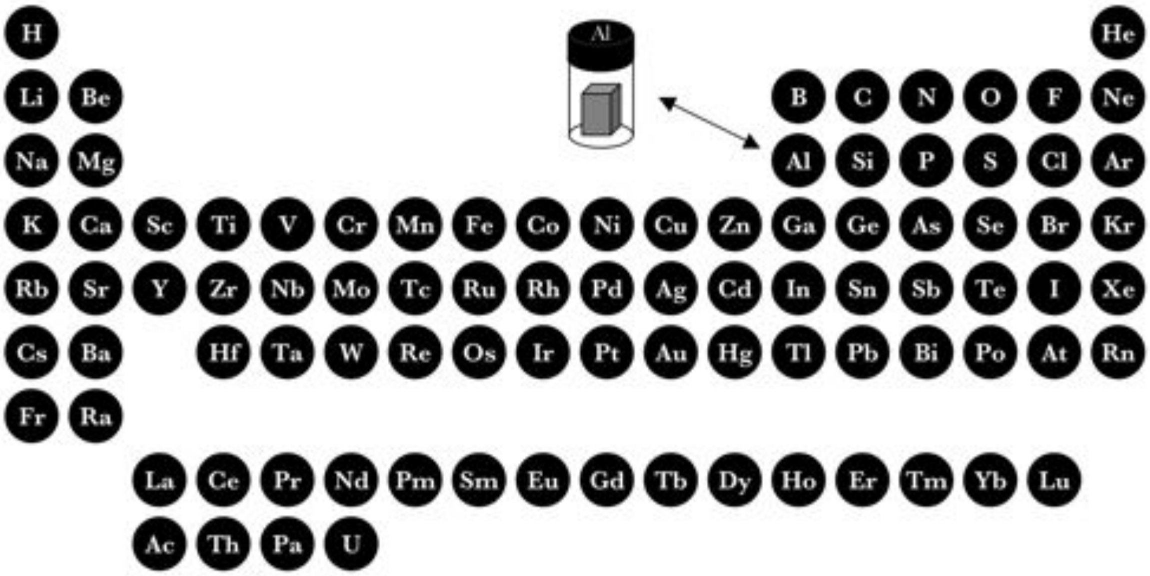

Figure 9.22: A graphical representation of the Periodic Table of 92 elements, as used in the Periodic Table Conjecture. Each element was presented inside a glass jar and placed in accordance with its position on the periodic table. The jar containing aluminium is shown from above in its Periodic Table position and from the side, revealing the contents within.

Within the Elements of Chance room we placed a physical periodic table of element samples (see figure 9.22) upon a table. The Element Collection was made by The Red Green and Blue Company Ltd. and contains all 92 naturally occurring elements within individual jars, the lids of which were marked with the symbol of the element it contained. Accompanied by an anglepoise lamp and a magnifying glass, the audience were encouraged to pick up the jars containing the elements, examine them, discuss them, and investigate the arrangement and contents of the table. An mp3 player loaded with Tom Lehrer's song *The Elements* was also provided for people to listen to whilst pondering the range of elements.

5. The Table of Improbable Objects

At the other end of the Beyond Surrealism room from the Microscopic Chess conjecture was The Table of Improbable Objects, a conjecture featuring a variety of items from the Materials Library collection. Each material was selected for its improbable nature and provided for the handling and wonderment of the audience. The following lists the contents of the table.

The contents of the conjecture was as follows: A piece of aerogel that it 99.8% air and is the lightest solid in the world, presented on a brass balance scale with a feather on the opposing side; Mica sheets of varying areas and thickness; hydrophobic sand and water; tin and zinc sticks that will 'cry' when bent; steel and aluminium rods for work hardening demonstration as the steel rod resists bending the more it is bent whilst the aluminium rod weakens the more it is bent and can be easily broken in two; an annealed copper rod that can easily be bent but only once; shape memory alloy; super-elastic glasses frames; brass block magic trick, magician's rubber sheet; magician's wax; magician's flesh colour putty; aluminium nitride wafer that conducts the heat from one's hand so efficiently as to allow one to cut through ice as if it were butter; and an auxetic material that thickens when stretched and becomes thinner when compressed.

6. Exercises in Materials Taxonomy and Relocation

This conjecture presented the Materials Cubes (see 9.3.1) in the form of a taxonomical game of arrangement that explored the perceived relationships between the cubes. The rules of the game were simple; players (minimum of two) may only move one cube per turn, turns must be taken consecutively around the table, and cubes cannot be removed from the gaming table. Each player may establish their own objectives and strategies to explore the spacial relationships between the Materials Cubes. At any stage in the process, or once a player has deemed themselves finished, they are able to take a photograph of their arrangement using an instamatic Polaroid™camera. The photographs taken were then displayed to document the multiple taxonomic arrangements achieved.

7. Beuysian Materials

Lightning with Stag in its Glare by Joseph Beuys (1958-85) is a large scale installation that incorporates forms cast from a number of metals. Beuys used a select palette of materials that were for him highly representative and symbolic. To accompany this work we offered the Beuysian metals. Sintered aluminium powder, aluminium alloy casting, aluminium ingot, polished aluminium extrusion with visible crystals, brass rod, brass cup, extruded brass bar, tin bronze bar, gold leaf, lead rod, lead shot, copper sheet, copper shim, copper cup with tin rim, copper powder, copper spheres, copper chips, copper funnel, welded steel bar, high carbon steel, woods metal, gallium, large wrought iron key, iron spheres, rusted iron drill bit with a tungsten carbide tip, cast iron utility access cover, and pig iron. Each item was offered for free handling and examination by visitors.

8. Viscoelastic Liquid

In front of Francis Bacon's triptych of paintings entitled *Three Studies for Figures at the Base of a Crucifixion* (1988) we placed a 9Kg (20lb) mass of the original flesh coloured silly putty. The audience were encouraged to handle, push, pull, bounce, twist, stretch, and generally play with the viscoelastic liquid in any way they wish. When not being handled the material was left to puddle freely in the middle of the room.

9. Ferro Fluid

The Ferro Fluid conjecture was presented alongside Salvador Dali's painting *Metamorphosis of Narcissus* (1937), described in the blurb as depicting a pool of liquid and metamorphosing forms. The conjecture consisted of a purpose built acrylic trough (210mm x 300mm) containing ferro fluid to a depth of 1cm and sealed with silicon. To accompany this a selection of magnets of different shapes and strengths were provided. The trough was raised up so that people could reach under the fluid and apply magnets to the underside of trough and reveal the forms created within the liquid that were indexical to the the lines of magnetic force.

10. Stethoscope

As in the previous Stethoscope conjecture, for the duration of the evening five stethoscopes were available for people to take around the gallery and listen to any conjectures, as well as any other surface they wished to place the stethoscope against. For the majority of the time this was against each other, drawing attention to our material presence.

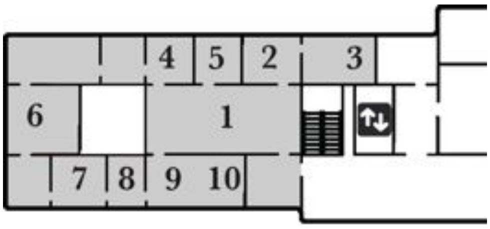

Figure 9.23: Floor plan of the States of Flux gallery of Tate Modern, Level 5, West. The numbers indicate the location of each Conjecture.

States of Flux Conjectures

1. Crystals

The States of Flux gallery contained a large room dedicated to Cubism, Futurism, Vorticism (room 2). This room played host to a conjecture that explored the phenomena of crystal structure and growth. A number of organic and inorganic crystals were available for people to handle, examine under microscopes and even make. For example, liquid nitrogen, bananas and cream were provided for the creation of a fine crystal banana ice cream. Other items presented in the conjecture were as follows: amethyst, clear quartz, smoke quartz, citrine crystal, white and brown sugars in caster, granulated and cube forms, unrefined demerara sugar, unrefined muscovado sugar, table salt, rock salt, black salt, sea salt, road gritting salt, halite salt, 'crystal garden' growing kit, aluminium extrusion with polished cross section revealing crystals, single crystal jet turbine engine blade, and spray-on theatrical frost that grew crystals when sprayed onto glass and heated with a hair dryer.

2. Fuels

Room 12 in States of Flux was entitled "USSR in Construction" and contented a large number of lithographs dedicated to the power and might of the the Soviet State. Nicholai Troshin's image *Builders of Socialism, Watch This Great Work Being Carried Out!* (1931), for example, depicts monumental factories and coal mines as a heroic constructivist backdrop against which workers engage in mechanised agriculture. Within this room the Fuels conjecture was located and consisted of a collection that explored the nature of materials that are exploited for their high energy content, such as coal and uranium, to those materials that contribute to fuel-cell technologies. The chemical mechanisms of these political materials will be demonstrated whilst also providing the participants with the opportunity to get up close and personal with those materials that are consumed in the generation of power. The conjecture specifically included: a

10Kg lump of coal, raw jet, polished jet, a raw peat sod, a peat brocket, a solar powered robot, commercial wood pellets sold as fuel, wood chips, a jar of petrol, a jar of diesel, a zinc bar, a lead bar, a vial of hydrogen, uranium glass, uranium ore, and a Geiger counter.

3. Shininess v Dullness

The Richard Hamilton room contained the Shininess verses Dullness conjecture that explored the nature of these two visual properties. Hamilton's works *Interior II* (1964) and *Toaster* (1967) used a variety of media to produce a range of finishes of varying levels of shininess. This conjecture offered the opportunity to compare and contrast differing shiny and dull surfaces and ask what is more shiny, a metal or a plastic? What role does polishing play? And what is happening at the molecular structural level that causes a material to be either shiny or dull? The following lists the items presented in this conjecture: aluminium foil, aluminium ingot, aluminium extrusion, anodised aluminium computer body, large and small glass spheres, glass window pain, windscreen repair fluid, mirrored acrylic, white acrylic sheet, brass sheet, copper sheet, copper rod, copper powder, large copper sphere, raw jet, polished jet, antique and new mirror, garnet rock, polished garnet, wet clay, dry clay, tile coated in 'NASA Super Black', pewter tea pot, lead pipe, carborundum powder, lint free polishing cloths, lens cleaner, Brasso metallic polish and a microscope.

4. Sweeties

The Sweeties conjecture was displayed in front of Marin Parrs, *Common Sense* (1995-1999) –a photomontage of 88 highly saturated colour photographs[7] taken by Parr at British seaside resorts. In each of the photographs the subject fills the frame and can comprise a detail or fragment of a larger subject like a Mr Whippy™ice cream, a fried breakfast or the icing of a cake. The overall effect of the montage is of an overwhelming sea of images that both excite recognition and delight as well as repel with lurid synthetics. To accompany this work, 88 different types of penny sweet were provided for people to eat.

The 88 different types of penny sweet were: ABC letters, anglo bubbly, aniseed balls, apple sours, bananas, beer pint pots, black jack chew, brusier chews, bubbaloo, bubble-gum balls, candy cones, candy necklaces, candy sticks, cherry lips, chocolate candy footballs, chocolate mice, cola bottles, crocodiles, dolly mixtures, drumsticks, edible paper, fish 'n' chips, fizzers original, fizzy cola bottles, fizzy cola dynamite sticks, fizzy fish, fizzy strawberry dynamite

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[7] Parr's *Common Sense* project comprises of 350 photographs in total, though only 88 were displayed by Tate Modern at any one time.

sticks, floral gums, flying saucers, foamy strawberries, freaky fish, fried eggs, friendship rings, fruit chews, fruit pastilles, fruit salads, fruity frogs, giant strawberry, gob-stoppers, gold bears, happy cherries, jelly alphabets, jelly babies, jelly beans, jelly bones, jelly fangs, jelly heart throb, lager tops, lassoes cola, liquorice cream rock, liquorice gums, liquorice whips, love heart mini rolls, marshmallows, marshmallow ice creams, marshmallow mushrooms, marshmallow strawberries, midget gems, milk bottles, milk teeth, millions, nerds, Parma violets, Pontefract cakes, porky pigs, rainbow dust, refresher lollies, refreshers, rhubarb and custards, rhubarb and custard lollies, sherbet, shrimps, skiffle disc chocolate, skiffle disc creme, skull crushers, smarties, snakes, sour cherry lollipops, spinning tops, sports mixture, strawberry milkshakes, super reds, sweet comforters, swizzles double lollies, terrific turtles, terror eyes, white mice, wine gums.

5. White Papers

In the instillation *Drawing Room* (1998), the artist Tomoko Takahashi covered every wall of the room with pieces of paper, upon which she had blacked out every word with a black felt-tip pen. In the centre of this room the White Papers conjecture was placed, consisting of a selection of many different types of white paper from tissue paper, heavy watercolour and cartridge paper to rice paper, recycled papers, and raw news sheet paper. The range of papers served to illustrate the wide variety of materials effects, finishes and surface textures that can exist within the category of white paper. An ultraviolet light was provided in order to examine the range of fluorescent whitening agents added to papers to make them appear 'whiter than white'. A spectrometer was also available for people view the spectrum of light that was reflected of the papers under the natural lighting conditions of the gallery.

The following is a list of the different white papers shown as part of this conjecture (in most cases 3 sheets of each type was provided). White toilet paper (Andrex™), recycled toilet paper (Sainsbury's™), kitchen towl (Tesco's™), linen paper, cotton paper, white printer paper (City Paper™), starlight (Artoz™papier), lucio ((Artoz™papier), Ali Baba Silver Flex (Artoz™papier), Ali Baba Shell (Artoz™papier), cartridge card (Artoz™papier), cartridge paper (Artoz™papier), Ali Baba Bright White (Artoz™papier), 1001-211 (Artoz papier), Perle (Artoz™papier), Toscana (Artoz™papier), SamsetX (Artoz™papier), Ivory Card 400g, Ice White, 150g (Canford™), Snow White 068, 150g (Canford™), Mi-Teintes White 100gms (Canson™), pack of Epson™photographic printing paper, white cotton rag paper (Khandi™), news print paper, white No. 63 (Clairefontaine™), shiny laminated white paper, tracing paper, fluted card, Pablo paper (Artoz™), and edible rice paper.

6. Rapid Prototype

Room 7 of the States of Flux gallery was entitled *Pop* and contained works by prominent Pop Artists of the 1950s and 60s like Andy Warhol, Jasper Johns and Roy Lichtenstein. In the centre of this room, adjacent to Andy Warhol's sculpture *Campbell's Tomato Juice Box* (1964) the Rapid Prototype conjecture was located. Warhol's work was often a comment on modes of mechanical production, reproduction and objects of mass consumption. The Rapid Prototype conjecture introduced contemporary modes of production and reproduction and provided the audience with the opportunity to handle and discuss the following collection of rapid prototype objects: a rapid prototype castle chess piece in nickel bronze, a rapid prototype mechanical fitting in steel, a rapid prototype latticework sphere of nickel sintered powder, a 3D printed section of nylon chain-mail, UV cured resin, 3D printed logo, stereo lithography resin UV cured, polypropylene 3D routing Logo, nylon 3D printed cable tidy, a rapid prototype ABS 4cm cube, a paper prototype 4cm cube and three love spoons made at Cardiff University in the following three materials: watershed somos 9120, white ABS, and white polyamide.

7. Materials Cubes

As with the first Materials Cube conjecture in the Materials Gesture gallery, this conjecture presented all sixty of the $4cm^3$ Materials Cubes for the audience to handle. The array of cubes was presented along side Auguste Rodin's iconic marble sculpture *The Kiss* (1901–4). The image of the sculpture and its cool, solid, smooth and heavy presence is inextricably linked to it being carved from marble with the two figures emerging from their rocky base as a statement of the sculptor's mastery over the material. In handling the array of Material Cubes, people were invited to consider the effects of material on the perception forms, the difference in thermal conductivity between materials and the range of methods that would be implied in the purposeful removal and shaping of material that constitutes carving.

8. Lead Bugle

For this conjecture two bugles of differing materials but identical dimensions were presented at the entrance to Christian Marclay's video instillation *Video Quartet* (2002) in which snippets of feature films in which a musical instrument is being played, are edited together into a multi-screen composition of sound, performance and cultural archiving. The first bugle was an old post office bugle made from copper-brass and was already in the possession of the Materials Library before the event but the second bugle, made from lead, was specially commissioned for the conjecture and made by master craftsman Rex Garrod. Audience members are invited to play both bugles and compare the differences in the sounds produced.

9. Tuning Forks

The Tuning Forks conjecture was located at the exit of Christian Marclay's *Video Quartet* and consisted of a selection of specially made tuning forks that were identical in their dimensions but varied in the materials from which they were made. They were made in the image of a standard steel tuning fork and designed to produce the pure note of a 440Hz A. The audience were free to play all of the forks and compare the frequencies and tonal qualities produced by each of the materials. The materials from which the other bespoke forks were made were as follows: stainless steel, mild steel, copper, zinc, brass, lead, solder (60% tin, 40% Lead), acrylic, tufnol, food-grade nylon, spruce, balsa, obeche, bass, walnut, ironwood, furniture grade birch plywood and glass.

10. Stethoscope

As in the previous Stethoscope conjectures, for the duration of the evening five stethoscopes were available for people to take around the gallery and listen at will to the sounds and surfaces of conjectures and each other. The presence of the bugles and the tuning forks afforded the opportunity for people to overtly investigate the inner and outer sounds of materials.

Idea and Object Conjectures

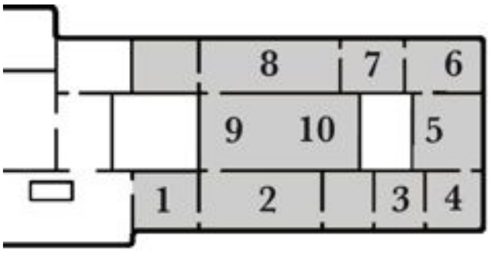

Figure 9.24: Floor plan of the Idea and Object gallery of Tate Modern, Level 5, East. The numbers indicate the location of each Conjecture.

1. Polish and Patina

Carl Andre's work *Venus Forge* (1980) was located on the floor of the first room of the Idea and Object gallery. It consisted of two rows of square steel plates laid side by side for a length of

15.5 meters. In between the two rows of steel was a row of smaller but similarly square copper tiles. The overall effect was a 1.2 x 15.5 meter carpet of metal that visitors were free to walk on as they moved across the space. Although this meant the work was touched by the shoes of visitors, the gallery prohibited the touching of the work by bare flesh. The reason for this was that the acidity of the oils and sweat of skin were corrosive to the work and fingerprints would readily oxidise the surface of the copper. The conservation team were very keen to clean the work as little as possible as the act of cleaning is the removal of the surface layer of material and thus, over time, the removal and degradation of the work. In order to highlight this and explore the nature of systems of patina and polish, 20 solid copper tiles in varying stages of oxidisation were presented as the Polish and Patina conjecture along side Andre's work. The conjecture offered visitors the opportunity to attempt the creation of accelerated patina and the removal of oxides with the following products; lemon juice, ketchup, baking soda, vinegar and a range of preparatory cleaners and cloths.

2. Touch Box II

In front of Piet Mondrian's painting *Composition C (No.III) with Red, Yellow and Blue* (1935) we placed the five hole touch box (see figure 9.17) that was previously used in the Materials Gesture gallery. Mondrian's painting offered a highly structured geometric exploration of the balance of colour and form. To accompany this visual input, the following materials were selected for inclusion within the touch box in order to provide haptic contrasting and complimenting sensations: a sod of fresh turf, viscoelastic liquid, sugar cubes, granulated sugar, and large flint rocks.

3. Black and White Tables

Sol LeWitt's work, *Six Geometric Figures (+Two) (Wall Drawings)* (1981) had been painted around the entirety of a room within the Idea and Object gallery. A work created from the following instructions written by LeWitt, the monochrome wall drawing filled with walls from floor to ceiling and created an overwhelming optical effect in black and white.

> ON FOUR BLACK WALLS, WHITE VERTICAL PARALLEL LINES, AND IN THE CENTRE OF THE WALLS, EIGHT GEOMETRIC FIGURES (INCLUDING CROSS, X.) WITHIN WHICH ARE WHITE HORIZONTAL PARALLEL LINES. THE VERTICAL LINES DO NOT ENTER THE FIGURES 1980–81.[8]

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[8] As cited by Tate Modern on the accompanying blurb, located at the entrance to the wall drawing room of the Idea and Object gallery, November 2006.

The Black and White Tables conjecture was located in the centre of the LeWitt room and consisted of two apposing tables; one covered in white table cloth displaying white objects and the other covered in black cloth displaying black objects allowing for the comparison of blackness and whiteness. In isolation one may agree that something is black or white, but when placed with other items also independently deemed to be black or white, the stated blackness or whiteness of the object may be called into question.

The following were black objects included on the black table: coal, tarmac, thermochromic sheet, polyurethane, polystyrene ball coated with graphite powder in a polyurethane resin, nylon 66, carbon fabric, carbon fibre, Bakelite™telephone, single crystal turbine jet engine blade, scopas modelling wax, glass from a welding mask, vulcanised rubber tile, privacy film, onyx sphere, silicon nitride sphere, black gloss ceramic tile, black satin finish ceramic tile, Nitinol wire, polyurethane clip, Plasterscene, Fimo, leather clutch bag, polished jet, raw jet, tile coated in 'NASA Super Black', 1 ml total black paint, A4 perspex acrylic, black pigment, graphite powder, thermochroic rubber duck, cooking utensil, eraser, felt-tip pen, nail polish, shape memory wire, bicycle inner tube, and leather gloves.

The following were white objects included on the white table: Kaolin, sticks of chalk, polyethylene tensile test specimens, tampon, glass ceramic positive mould for the creation of a womans size 7 1/2 marigold glove, high density polyethylene, instant snow, bio-active glass scaffolds, thermal till roll, liquid latex, polystyrene packing pellets, paraffin wax, plaster casting of upper teeth, PVA glue, biodegradable starch packing pellets, nylon fibber composite, polystyrene balls, a selection of white papers (as see in a previous conjecture but presented in a bundle), sintered ceramic disc, cuttlefish, keraflex ceramic sheet, A4 perspex acrylic, sugar cubes, granulated sugar, caster sugar, table salt, rock salt, plain flour, self-raising flour, 'floam' play dough, polymorph, feathers, talcum powder, eraser, shaving brush, ice cube tray, plaster of Paris teeth, biodegradable and non-biodegradable disposable spoons, nail polish, ping-pong ball, cotton rag, porcelain tea cup and saucer, and a three pin plug.

4. The Essence of Fluorescence

The Essence of Fluorescence conjecture was situated in the Dan Flavin room in between the two works *Monument for V. Tatlin* (1966-69) and *The Diagonal of May 25* (1963). The conjecture drew its contents primarily from The Essence of Fluorescence exhibition staged previously at the Hayward Gallery (see 9.2), originally devised to accompany the show *Dan Flavin: A Retrospective.*

Instead of being presented behind glass (as in the original Essence of Fluorescence cabinets), each item of fluorescent interest was freely available for people to handle and view under a variety of UV light sources. Two hand held UV tube lights, two pocket sized UV LEDs and one specialist viewing chamber designed for the viewing fluorescent materials, under both short and long UV wavelengths, without damaging the eyes.

The following lists each of the fluorescent items within the conjecture. Molar tooth, live-edge perspex, fluorescent paint balls, phosphorescent paint, UVA / UVB sunscreen, concentrated green fluorescent protein (GFP), addamite, franklinite, willamite, calcite, spinel crystal, manganocalcite, amber, tonic water, live-edge perspex propelling pencil, washing powder, Father Christmas stamp, UK 1st class stamp, nativity stamp, synthetic ruby, scorpion, fluorescent glass fruit bowl, £20 note, floored diamonds, fluorescent stage make-up, parmesan cheese, Nile red molecule in solutions of varying polarities, soap, fungus, and orange, red, pink, blue, green and yellow fluorescent paints.

5. Need Do Nothing

For this conjecture we simply printed a sign and hung it on the curtain that cloaked the entrance of Cildo Meirele's instillation *Eureka/Blindhotland* (1970-5). The following text was written upon the sign:

> It became clear to us when constructing this conjecture that there was nothing we wanted to add to the space. On entering the room Zoe could tell by the sounds playing, what material the spheres were made from. Mark came to the same conclusion but used his nose to detect the material. Martin however attempted to deduce by sight what the material was but was initially mistaken.
>
> Without reading the description on the wall inside this room, see if you can work out: WHAT MATERIAL ARE THE SPHERES MADE FROM?

6. He Equilibrium

The He Equilibrium conjecture was designed to accompany Jeff Koons' *Three Ball Total Equilibrium Tank* (1985), a tank of saline solution containing three basketballs in a state of neutral buoyancy. The conjecture consisted of a packet of white-tac adhesive, a set of digital scales and five large white balloons filled with helium and printed with the periodic table symbol for helium 'He'. A long string, greater than the height of the ceiling, was attached to each balloon so that when the balloons floated upward they could be retrieved. The audience were encouraged to attach amounts of white-tac to the strings in order to achieve a neutral buoyancy where a balloon would hover in mid air, neither rising or falling. If people wished they were able to use the the scales to estimate the amounts of white-tac needed or reveal the weight of white-tac used to counterbalance a balloon.

7. Lead Bugle

As with conjecture 8 in the States of Flux gallery, the lead bugle was presented with the copper-brass bugle for people to play singularly or as a duet and compare the different properties of the two instruments. In this instance, the conjecture was placed in conjunction with Christopher Wool's untitled work that exclaims in large black capital letters "YOU MAKE ME", a statement on completion and the coupling of two or more entities to make a whole. In the case this conjecture this could be read as two players in a duet, a single player and the instrument and the materials and the instrument.

8. Beuysian Materials II

Many of the materials Beuys used were for him invested with symbolic associations derived from science, politics, anthropology and his own life. He often used organic materials that were prone to deterioration, seeing this process of transformation and change as essential to his work. The Beuys room in the Idea and Object gallery contained a number of works by Beuys including *The Pack* (1969), *Felt Suit* (1970) and five vitrines of artefacts Beuys collected. Within this room the Beuysian Materials II conjecture was located and in addition to the Beuysian Materials shown in the Poetry and Dreams gallery, the following materials were also presented for people to handle. White, milk and and dark chocolate, selection of leathers, raw sheep's wool, treated wool, shrunken woollen jumper, felt, honey, honey comb, bees wax, pollen, pig fat and goose fat.

9. Shimmer Swatch

This conjecture saw the return of the Shimmer Swatch of the shiniest aluminium in the world, previously experienced in the Material Gestures gallery. The pieces of aluminium, each cut to one of the 'A' sizes, were presented along side Robert Morris's sculpture in the Around Minimalism room, *Untitled* (1965/71), that consisted of four large mirrored glass cubes (914 mm^3). Participants were able to explore the nature of the reflections produced and the optical effects created by the relationship between material, geometry, figure, and space.

10. Materials Cubes

The Materials Cubes, as previously presented in the Material Gestures and the States of Flux galleries, were this time contextualised by their location within the Around Minimalism room that contained works which explored the cuboid form in a variety of sizes and materials. In particular, Donald Judd's works *Untitled* (1972) –a stack of 10 cuboids hung on the wall of the gallery, and *Untitled* (1980) –a copper box with an internal enamel surface.

Poster

Figure 9.25: Poster image created for *Materials Library Presents... Tate Modern*

The image in figure 9.25 was made by placing a number of items from the Materials Library collection on a flat bed scanner and inserting logos using PhotoShop™. The image was created to serve as a poster for the *Materials Library Presents... Tate Modern* event and was used in both Tate and Materials Library publicity material. For the event the image was printed at A0 size (841 x 1189 mm) and placed in an A0 light box that was placed at the entrance of each gallery space on each of the four nights.

Booklet

A 26 page, A5 sized booklet was created as an accompaniment to the entire *Materials Library Presents... Tate Modern* event, offering an overview of the project, information on particular materials and thematics found within the conjectures and an annotated map for each of the evenings, locating each of the conjectures on offer. This publication was given on arrival to those in attendance in exchange for their ticket. A scanned copy of the booklet can be viewed in Appendix C of this thesis.

Badges

Materials badges were made as gifts for the event participants and consisted of a piece of material with a fastening pin glued onto the back of it, as represented in figure 9.26. Four different types of badges were presented each evening for people to pick and wear. For the Material Gestures gallery, rectangular tiles of the shiniest aluminium in the world, duck down feathers, squares of clear acrylic coated with deep blue thermochromic paint, and a composite of shredded compressed plastic were made into badges. For the Poetry and Dream night, chunks of foam, pieces of woollen cavity wall insulation, ceramic tile and white sugar cubes (see figure 9.26) were turned into material badges. For States of Flux the following four materials were used; coal sealed with PVA glue, a selection of different white papers, the shiniest aluminium in the world and sugar cubes. And finally, for the Idea and Object gallery, tiles of fluorescent live-edge acrylic, strips of copper sheet, pieces of woollen cavity wall insulation, and coal were used to make the material badges.

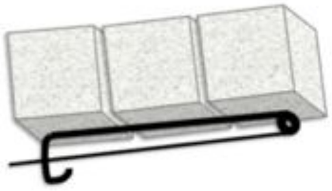


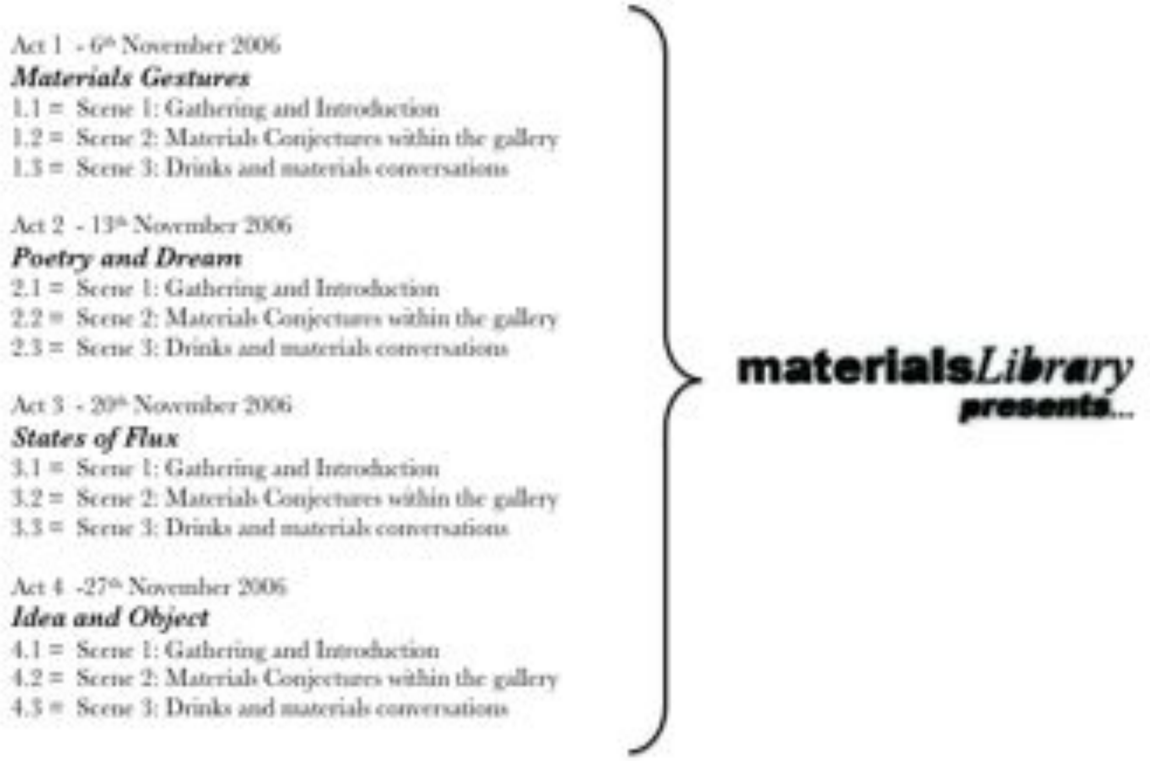
Figure 9.26: A graphical representation of one of the sugar cube badges made for the Poetry and Dream and States of Flux evenings.

Conjecturers

A team of eight helpers (known for the event as Conjecturers) were selected, trained and organised to supervise specific Materials Conjectures on each of the nights. 52 applications were received from people wishing to participate as Conjecturers and the final 8 were selected primarily because of their ability to communicate ideas and engage with non-experts. The Conjecturers came from a variety of materials-related backgrounds and took part in an afternoon training session, finishing with a team meal. The aim of the training session was to introduce the Materials Library methodology and mode of communication, as well as form a strong group who could work well together as a team. Before each evening, each Conjecturer was provided with an information pack about the specific Materials Conjecture they had been assigned to for that evening. The role of the Conjecturers was not only supervisory, but where needed, to act as catalysts for the reactions between audience members, the materials, the art and the science presented within Conjectures.

At the events, each conjecturer was required to wear black and issued with a black t-shirt with the *Materials Library Presents* logo stitched on the front of the garment at the bottom left corner. The black clothing and matching t-shirts served as a uniform that subtly distinguished the Conjecturers from the visitors and tied them into the motif of the black cloths used to cover the Conjecture tables.

9.3.2 Event



Act 1 - 6th November 2006
Materials Gestures
1.1 = Scene 1: Gathering and Introduction
1.2 = Scene 2: Materials Conjectures within the gallery
1.3 = Scene 3: Drinks and materials conversations

Act 2 - 13th November 2006
Poetry and Dream
2.1 = Scene 1: Gathering and Introduction
2.2 = Scene 2: Materials Conjectures within the gallery
2.3 = Scene 3: Drinks and materials conversations

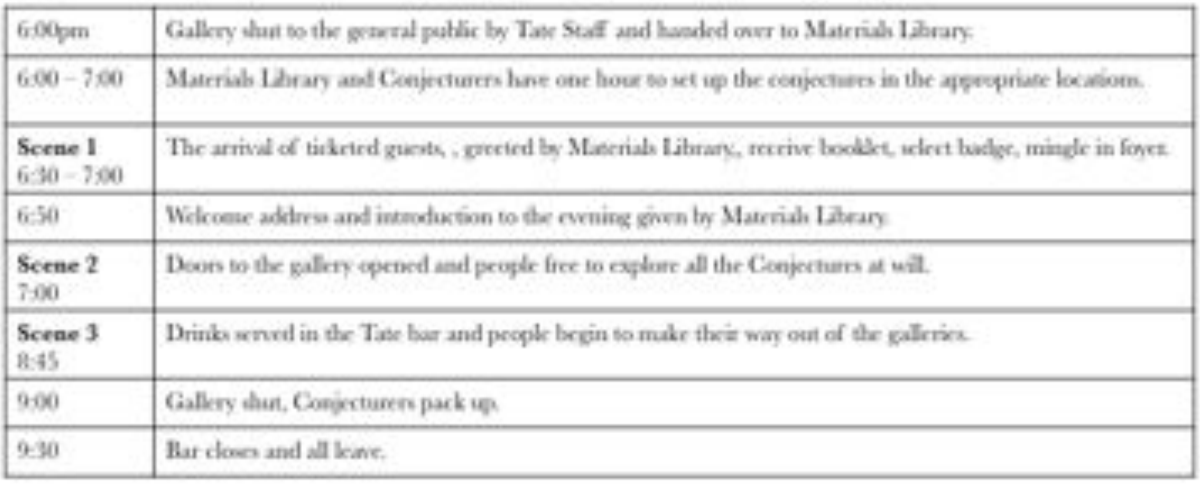
Act 3 - 20th November 2006
States of Flux
3.1 = Scene 1: Gathering and Introduction
3.2 = Scene 2: Materials Conjectures within the gallery
3.3 = Scene 3: Drinks and materials conversations

Act 4 -27th November 2006
Idea and Object
4.1 = Scene 1: Gathering and Introduction
4.2 = Scene 2: Materials Conjectures within the gallery
4.3 = Scene 3: Drinks and materials conversations

Figure 9.27: The Act and Scene structure of the *Materials Library Presents... Tate Modern* event, with the date of each evening given.

Enabling each of the four evenings to be considered a separate occasion, whilst simultaneously alluding to a coherent whole, the *Materials Library Presents* event was framed using an act and scene structure, with the four nights being four acts, each containing three scenes. This also served to underline the theatricality of the project and the performative nature of the engagements that were provided for the public. Figure 9.27 illustrates this act and scene structure and was provided at the front of the booklet that was given to participants on arrival.

Each evening relied upon prior organisation, logistical planning and time management, as the *get-in* time was short and the task ambitious. Figure 9.28 outlines the time table that was worked to during each of the four evenings. The greatest difficulty faced was the limited time available for setting up. No materials could be bought into the gallery space until 6pm as prior to this the space was open to the general public. This meant that there was a maximum of an hour in which to set-up the evening's Conjectures and prepare the space for the arrival of the public. Each Conjecture was charged with setting up their particular Conjecture and once completed, help any fellow Conjecturer who had not yet finished.



6:00pm	Gallery shut to the general public by Tate Staff and handed over to Materials Library.
6:00 – 7:00	Materials Library and Conjecturers have one hour to set up the conjectures in the appropriate locations.
Scene 1 6:30 – 7:00	The arrival of ticketed guests, , greeted by Materials Library., receive booklet, select badge, mingle in foyer.
6:50	Welcome address and introduction to the evening given by Materials Library.
Scene 2 7:00	Doors to the gallery opened and people free to explore all the Conjectures at will.
Scene 3 8:45	Drinks served in the Tate bar and people begin to make their way out of the galleries.
9:00	Gallery shut, Conjecturers pack up.
9:30	Bar closes and all leave.

Figure 9.28: outline of the time table for the creation of each evening of the *Materials Library Presents... Tate Modern* event.

Due to the capacity of the galleries and the desire to provide each visitor with the time and space to encounter each conjecture, Tate made available only 100 tickets for each of the four acts. In every occasion, all acts were sold-out prior to the commencement of the evening and cost £10 each (£8 for concessions).

Scene 1

Scene 1 of each of the four acts followed the same format and differed only by the type of material badges handed out and the gallery space outside of which it took place. In every instance, audience members gathered in the foyer area outside of the designated gallery space. The Materials Library team (Martin Conreen, Zoe Laughlin and Mark Miodownik), dressed in formal evening attire, circulated with trays containing the material badges and exchanged people's ticket for a *Materials Library Presents... Tate Modern* booklet. Figure 9.29 shows badges and booklets being handed out in Scene 1 of both the Poetry and Dream and Material Gestures acts. People were free to select any materials badge that took their fancy and engage in a little discussion as to the nature of the material they selected.

Figure 9.29: Badges and booklets being circulated in Scene 1 by Zoe Laughlin (left), Mark Miodownik (centre) and Martin Conreen (right).

Whilst some people attended with friends, others came on their own and Conreen, Laughlin and Miodownik took the opportunity of Scene 1 to work the room as the hosts of the evening; introducing audience members to each other, initiating conversations and using the selection of a common badge as a way to break the ice between audience members who did not know each other.

During the course of Scene 1, Laughlin and Conreen would take it in turns to enter the gallery and check on the progress of the Conjectures' installation. The Materials Library's assistant, Jennifer Horrocks, who had worked closely with Laughlin during the making of the Conjectures prior to the event, was stationed within the gallery for the duration of the night and would bring to the attention of Laughlin or Conreen any queries with regard to the set-up of the Conjectures.

Once everyone had arrived, selected a badge, received a booklet, and the readiness of the Conjectures and Conjecturers within the gallery had been signalled, an introductory address was given by Materials Library. The gallery doors were then opened and audience members free to explore the rooms at will and reminded that for one night only it was "please do touch"[9].

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[9] The ubiquitous gallery adage of "please do not touch" abandoned for the hands-on celebration and exploration

Scene 2

In each of the four acts, Scene 2 is characterised by the audience freely circulating throughout the gallery exploring the Conjectures on offer, conversing with the Conjecturers and each other, as well as viewing the art of the Tate's permanent collection displays. The following documents a small number of particular occurrences promoted by specific Conjectures over the course the four acts of the *Materials Library Presents... Tate Modern* event.

Liquid Pillows meet Thermochromic Snail

Both the Liquid Pillows and the Thermochromic Snail conjectures were presented in the Material Gestures gallery (Act 1, Scene 2). After discovering the heat produced by the pillows of sodium acetate and the heat activated colour transformation of the Thermochromic Snail, some audience members combined the two conjectures. Figure 9.30 shows both the Liquid Pillows and Thermochromic Snail conjectures, as well as the Pillows being placed onto the surface of the Thermochromic Snail. Such a coupling of conjectures shows the playful experimentation and investigative attitude of the audience.

Figure 9.30: Left: The Liquid Pillows Conjecture. Centre: The Thermochromic Snail on the floor of the gallery in front of *The Snail* by Henri Matisse. Right: A hot pouch of sodium acetate meets the Thermochromic Snail, leaving white rectangular areas of colour change.

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of stuff.

Materials Cubes meet He Equilibrium

Unplanned connections between conjectures can also be see in figure 9.3.2, where the Materials Cubes and the He Equilibrium Conjectures in the Idea and Object gallery (Act 4) were combined by audience members in an attempt to determine if there were cubes that would balance a helium balloon. Figure clearly shows 5 cubes attached onto the string of one balloon but it was not just the masses of cubes that were tested in this way. At one point in the evening, a balloon was taken to the Beuysian Material II Conjecture and a range of Beuysian materials hung from the balloon. It was also noticed that some cubes made their way, courtesy of inquisitive audience members, to the scales provided for the He Equilibrium Conjecture in order to discover the exact weight of specific cubes.

Figure 9.31: Left: Some of the 4cm x 4cm x 4cm Material Cubes. Centre: The He Equilibrium Conjecture where the audience were invited to measure out and attach small masses of Whit-Tac to the strings of balloons filled with helium in order to achieve a state of equilibrium. Right: The Materials Cubes are joined with a helium balloon by audience members.

Leaving Your Mark: The Blackboard and Whiteboard Conjectures

Unlike many of the conjectures on offer, both the Blackboard and the Whiteboard Conjectures did not offer a range of three dimensional objects that could be fondled, but rather a range of surfaces of the same colour but with varying qualities of finish to them. Over the course of the evening the material surfaces were seen to change as audience members left their mark upon the boards in either chalk or charcoal. Figures 9.32 and 9.33 each show their respective boards in their clean state, as well as some of the marks that were made upon them.

Figure 9.32: The Blackboard Conjecture presented in the Material Gestures gallery (Act 1). Left: The board in its clean state. Centre: A close up image of the intersection of 4 of the black paints showing the different textures of the surfaces and the saturation of chalk upon them. Right: The board at the end of the evening showing some of the marks made by audience members.

Figure 9.33: The Whiteboard Conjecture presented in the Poetry and Dream gallery (Act 2). Left: The board in its clean state. Centre: People making marks upon the board with charcoal sticks and discussing the different types of paint and their finishes. Right: An audience member passes the ultraviolet light over a section of the board to reveal the fluorescent whitening agents contained within the paint.

The images of the Blackboard in figure 9.32 in particular show the transformation of the board from the beginning of the evening to the end. No people are present in the images themselves but rather the marks made indicate that at some point people were present, that something has happened, and that an alteration in the material has occurred as a result of the actions of the audience. For both the Whiteboard and the Blackboard, the marks made upon them are not only a trace of the actions done to them but a revealer of the nature of the materials used.

Black & White Tables

The Black & White Tables Conjecture in the Idea and Objects gallery (Act 4), as shown in figure 9.34, was similar to the Blackboard and Whiteboard conjectures in that it explored the nature of these two shades but this Conjecture took the exploration into the realm of overtly three dimensional material and cultural objects.

Figure 9.34: The Black & White Tables Conjecture in the Idea and Objects gallery (Act 4). Left: A selection of some of the items on the black table. Centre: Some audience members regarding and handling items from the white table against the backdrop of LeWitt's wall drawing. Right: A selection of items on the white table.

At both tables people handled the items freely, exploring the haptic properties of the materials, exchanging stories evoked by the materials and set themselves the challenge of identification, often testing and asking other audience members what they thought of particular items. In this regard, this Conjecture is representative of the way in which many people behaved at a large number of the Conjectures in all of the Acts. Martin Conreen acted as the principle Conjecturer on this table and engaged audience members with stories and demonstrations, answering questions and revealing the varied nature of the materials present.

Silly Putty

The mass of viscose elastic material that was presented as the Silly Putty Conjecture in the Poetry and Dream gallery (Act 2) was the source of much audience engagement, enjoyment and physical manipulation. Figure 9.35 shows the Silly Putty in various states of manipulation. As seen with the Materials Cubes, He Equilibrium, Liquid Pillows and Thermochromic Snail Conjectures, audience members felt free to push the boundaries of Conjectures and develop them in new and unplanned ways. As represented in the far right hand image of figure 9.35, the Silly Putty was rolled and stretched like a giant sausage and spread into other rooms of the gallery by co-operating audience members.

Figure 9.35: The Silly Putty Conjecture in the Poetry and Dream gallery (Act 2, Scene 2). Far Left: Contorted Silly Putty with a Francis Bacon painting in the background. Left: Close up of the Silly Putty with lumps, bumps and fissures created as the result of manipulation by audience members. Right: Audience members pushing and pulling the putty. Far Right: The Silly Putty after being stretched through the gallery by audience members.

A Duet for the Lead Bugle Conjecture

The Lead Bugle Conjecture appeared in both the States of Flux (Act 3) and the Idea and Object galleries (Act 4). In both cases it was a chance for people to play the copper-brass and lead bugles and experience the differences between the two instruments and the materials from which they are made. On both nights, a number of audience members who declared an ability to play the trumpet were able to play a tune on both instruments and attempt a methodical comparison of the sounds produced by the two instruments. More proficient payers also willingly helped less experienced and able people to achieve a note from the instruments. On more than one occasion people attempted to play The Last Post –a piece of music traditionally played on the bugle and in the Idea and Object gallery (Act 4) this piece was even played as a duet and captured in the photograph seen in figure 9.36. Throughout the Lead Bugle Conjecture, unconstrained by ability, audience members overtly performed for and to each other, demonstrating their participation in the Conjecture.

Figure 9.36: Two audience members playing a duet on the lead (left) and brass-cooper (right) bugles in the Idea and Object gallery.

Taste Me, Smell Me: The Crystals, Sweets and Fuels Conjectures

Figure 9.37: The liquid nitrogen ice cream being made and eaten as part of the Crystals Conjecture in the States of Flux gallery (Act 3). Far Left: Liquid nitrogen being decanted into a dewar for use in making crystals and specifically ice cream. Left: Mark Miodownik mixing cream and sugar together in preparation for the pouring on of liquid nitrogen. Right: Banana being dipped into the dewar. Far Right: Audience members tucking into the freshly made ice cream.

On the evening of Act 3 in the States of Flux gallery there were two Conjectures that prompted audience members to not only handled elements of the Conjecture but taste them as well. The Crystals Conjecture contained the making of ice cream using liquid nitrogen to freeze the ingredients extremely quickly, causing the formation of very small and fine crystals that give an extremely smooth texture to the ice cream. A number of images of the successful making and eating of the liquid nitrogen ice cream can be seen in figure 9.37. Eating was also encouraged in the Sweets Conjecture, depicted in figure 9.38, where 88 different types of penny sweets were offered for tasting. Whilst nearly all of the 100 audience members sampled the ice cream and would have happily eaten more, very few people ate more than three or four of the sweets. One person however, attempted to eat one of every sweet and by the end of the evening had managed to sample all of the different types provided.

Figure 9.38: The Sweets Conjecture in the States of Flux gallery (Act 3). Left: The Sweets Conjecture presented in front of Martin Parr's work *Common Sense*. Centre: An audience member eats a sweet. Right: The Materials Conjecturer tops up the white chocolate whilst audience members eat sweets and look on.

Figure 9.39: The Fuels Conjecture in the States of Flux gallery (Act 3). Left: A selection of the materials presented on the Fuels Conjecture table. Centre: An audience member smells a lump of peat. Right: A mass of raw coal presented on a purpose built tray on the floor, next to the Fuels Conjecture table.

The impact of the visual and flavoured aspects of the Sweets Conjecture was accompanied by the unexpected presence and power of the smell of the sweets. The whole room was filled with a heady sugary odour that underpinned the overwhelming synaesthetic nature of the Conjecture. The impact of smell was also experienced in the Fuels Conjecture where brochettes of peat, cans of petrol and jars of diesel gave an unmistakable smell to the space. The central image in figure 9.39 shows one audience indulging in the smell of the the peat, much to the delight of her companion. The image on the right of figure 9.39 shows the large lump of coal displayed as part of the Fuels Conjecture. A number of audience members commented on the surprising lack of smell emanating from the coal. It was agreed that as it left a clear physical residue, it was surprising to discover that, when compared to other carbon based substances that smelt very strongly, the coal was perceived to be completely without a smell.

Scene 3

Like Scene 1, the format and content of Scene 3 was essentially the same for all four of the acts. The audience made their way out of the gallery space and down to the Tate Bar on the ground floor where complementary drinks were served. Many people had made new acquaintances through the course of the evening and discussions ranged from the sharing of thoughts on the Conjecture experiences, to enquiries on backgrounds, materials interests and the exchanging of contact details. In the most part people reflected upon the experiences they had, shared observations and recounted their feelings, realisations, delights, and disappointments.

9.3.3 Aftermath

Feedback from both the Tate staff and the public who attended the evenings was very positive. For the public programmes team of Tate Modern, being sold out every night was important but the fact that many of the Conjectures engendered behaviours not normally seen within the gallery was deemed both valuable and exciting. The communal curiosity of the audience was praised by Conjecturers and Tate staff alike, along with the diversity of those in attendance. Participants included family groups with children as young as 11, further and higher education students of both the arts and sciences, and adults young and old alike: in other words a good cross-section of the population.

Information on those in attendance was gathered by a team of three ethnographic researchers from the Department of Education & Professional Studies, King's College London, who specialise in gallery and audience observations and attended all four of the events that constituted *Materials Library Presents*. As referenced in chapter 6.2, this team made notes throughout the evenings, took photographs (some of which have been used in illustrating this section of the thesis) and conducted semistructured interviews with a randomised sample of audience members.

A specific find of the ethnographic observation team was that many audience members attended multiple Acts, often coming to one evening, discovering it was part of a series, and then purchasing tickets to the remaining nights. A high level of interaction between audience members was observed on each night and a sense of community was established due to the fact that a fair number of people came to more than one event. More experienced audience members (those who had been to more than one night or had previously experienced the Conjecture earlier that evening) were observed leading by example and working with the Conjecturers to engender an inhibition-free environment where materials were explored in unexpected ways. This behaviour provides evidence for Meisner's assertion that "visitors take notice of or even study the actions of others in order to make sense of certain aspects of an exhibition and its functioning" (Meisner et al., 2007, p1535).

The following extract is from an email that was sent by an audience member after she attended the first night and subsequently came to two more of the evenings. Such direct written feedback was received as a result of the questionnaires that were available for audience members to fill in at he end of the night over a glass of wine or email back to the curatorial team of Materials Library at a later date. The sentiments expressed that related to the nature of a shared experience concur with much of the verbal feedback received from audience members, Conjectures and the Tate alike.

> "It was a most intriguing evening. My first thought concerns language. Some of the audience were using words rarely said in an art gallery - 'force', 'velocity', 'pressure', 'sound waves'. The whole language of the evening was different. In that [Tate] context I'm used to a vocabulary of art and think and communicate around 'form', 'colour' and 'spatial relationships' –a language for a visual medium. I kept hearing something quite different and eventually tried to start thinking along those lines too –moving out of my own box! Others were doing the same, moving out of their science boxes.... and the result was we were all out of our boxes, milling around in some middle space, using what vocabulary we could to talk about what we were seeing. I liked that very much –unusual, a bit taxing, and it needed thinking about. Thank you." (Email received from an audience member after attending Act 1, the Materials Gestures evening.)

Another audience member wrote the following feedback on their questionnaire by way of a reflection at the end of the Poetry and Dream evening. The performative nature of the event (of particular interest to (Meisner et al., 2007)) had clearly been absorbed by this person and it was pleasing to see that the theatrical style and format employed had been successfully interpreted.

> "I think what you've created is pure theatre rather than art, science, art/science or whatever. In fact you highlight the theatrical nature by using 'Acts', by dressing up and, even, by serving ice-cream! The participants are all actors as are the

> conjecturers; the materials are the props. Each participant brings their own stories and goes away with their own interpretations of what they've seen and heard. The galleries provide little more than beautifully constructed sets in most cases. Roll on next Monday." (Feedback from audience member after attending Act 2, the Poetry and Dream evening.)

A third audience member took the opportunity to comment on the Conjectures and their supervising Conjecturers, stating on their Tate feedback form:

> "I thought the range of activities was amazing. Like nothing I have done or seen before in a gallery. It really got me thinking, as did the people supervising. They were very knowledgeable and helpful. Providing me with just the right amount of information to peek my interest and get me to take part. (They were also very forgiving when I broke something –sorry). It is a difficult balance to strike and this event struck it... illuminating, fun, unexpected and I wish I had known before that it was a series as I would have come to more than one." (Feedback from audience member after attending Act 4, the Idea and Object evening.)

What Can The Matter Be?

As a result of the success of the *Materials Library Presents... Tate Modern* event, the Tate commissioned a podcast that aimed to capture something of the spirit of the original event and bring our approach to materials, science and art to an audio-guide. We were provided with a professional audio producer, Hannah Andrassy, who had worked previously with Tate on a number of audio tours. We worked with Andrassy to turn the knowledge and experience gained through *Materials Library Presents... Tate Modern* into an audio accompaniment for the material minded and incurably curious.

A central aspect of the success of *Materials Library Presents* was the conversations that took place within the gallery: from the consideration of art through the lens of materiality and how this is informed both by science as well as the arts, to the comprehension of new scientific ideas previously unconsidered in the context of the art gallery. A central aim of the podcast was to capture this diversity of subjects and consider a range of art works on display through our multi-disciplined materials lens.

Conreen, Laughlin and Miodownik took the lead as the devisers, writers and presenters of the podcast, pairing up to do conversational tracks, as well as doing some of the tracks singularly. In order to increase the range of voices heard as well as the breadth and depth of knowledge provided, guest tracks were recorded with the chemist Andrea Sella, the mathematician Marcus du Sautoy, and the artists collective Greyworld.

Figure 9.40: Investigating Manzoni's work *Artists Shit* for *What Can The Matter Be?*, tack 15. Left: The rim of the can is inspected using our microscope. Centre: Miodownik (left) and Conreen (right) discuss the contents of the can. Right: The can is viewed under a UV light.

To achieve our vision for some of the tracks we worked in partnership with the art conservators of the Tate Modern, who granted us permission to touch specific works and subject them to a number of physical investigations. We were, for example, allowed to brush the surface of Jean Dubuffet's painting *The Exemplary Life of the Soil (Texturology LXIII)* with a paint brush in order to record one of the sounds of the painting (for track 4). We were also granted access to Piero Manzoni's 1961 work *Artist's Shit*, in which the artist presented a can labelled "Artist's Shit" but did not reveal whether or not there was shit in the can. The track (track 15) was based around an attempt to determine through a variety of methods whether there was shit in the can or not. Documentation of the making of the can track is shown in figure 9.40.

The final podcast consisted of 18 tracks and was entitled *What Can The Matter Be?*. It was launched on the Tate website and iTunes on the 13th April 2007 and is still freely accessible to listen to online, or download, to this today. Figures 9.41, 9.42 and 9.43 shows the pages of the Tate website[10] that host the podcast and provide a way of experiencing the content on-line.

In order to promote the podcast Tate made a short film entitled "Pease Do Touch" that called for the re-staging of some of the *Materials Library Presents... Tate Modern* conjectures within the gallery and a discussion by Materials Library on the *Materials Library Presents* project. The film was released on Tate Shots, the Tate's flag ship video podcast that was in the top ten UK video podcasts for 2007.

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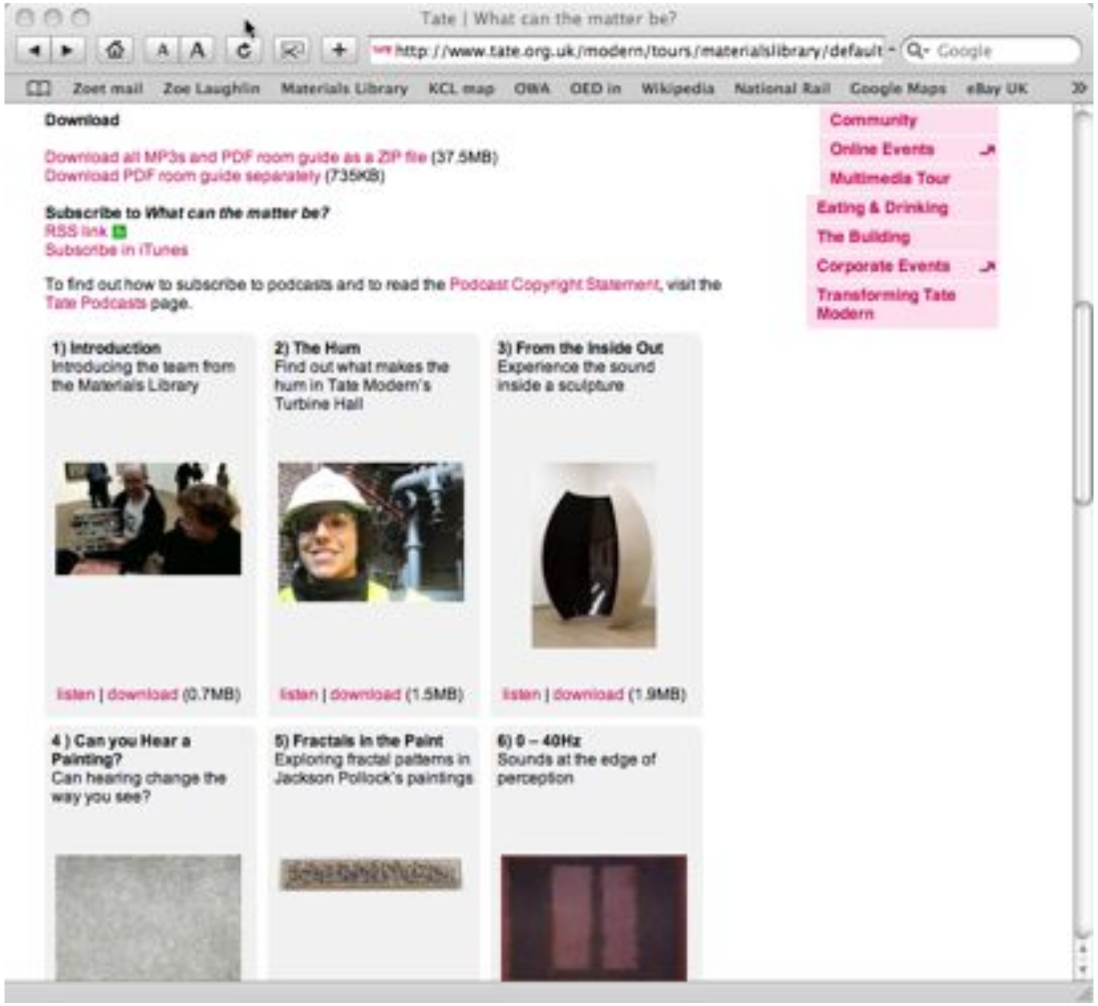
[10] *What Can The Matter Be?* on the Tate website: www.tate.org.uk/modern/tours/materialslibrary

Figure 9.41: Screen shot of *What Can The Matter Be?* on the Tate Modern website. The opening view of the site with the “Please Do Touch” film imbedded as a Flash video and the option to download all the tracks in the form of the bundled podcast.



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Download all MP3s and PDF room guide as a ZIP file (37.5MB)
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1) Introduction
Introducing the team from the Materials Library
listen | download (0.7MB)

2) The Hum
Find out what makes the hum in Tate Modern's Turbine Hall
listen | download (1.5MB)

3) From the Inside Out
Experience the sound inside a sculpture
listen | download (1.9MB)

4) Can you Hear a Painting?
Can hearing change the way you see?

5) Fractals in the Paint
Exploring fractal patterns in Jackson Pollock's paintings

6) 0 – 40Hz
Sounds at the edge of perception

Figure 9.42: Screen shot of *What Can The Matter Be?* on the Tate Modern website. Scrolled down from the opening view, the tracks are represented by a thumb nail image.

Figure 9.43: Screen shot of *What Can The Matter Be?* on the Tate Modern website. Once the user clicks on a thumb nail a page such as this opens with the image enlarged and the track provided for playing and downloading.

Figure 9.44: An iTunes screen shots showing the UK chart positions of the *What Can The Matter Be?* podcast in the iTunes store. *What Can The Matter Be?*, represented by a square orange icon, is at number 56.

1. What Can The Matter Be?
   Tate
2. Front Row Interview
   BBC Radio 4
3. TateShots
   Tate
4. Berry Bros. & Rudd Wine Pod...
   Berry Bros. & Rudd
5. Breakfast Show Podcasts
   Capital Radio
6. Books on Guardian Unlimited
   Guardian Unlimited
7. Topshop Podcasts
   Topshop
8. Radio 3 Arts Talk
   BBC Radio 3
9. Jamie's Podcast
   Jamie Oliver
10. TheKnowledge
    Times Online
11. "Heart of Darkness" Audiobo...
    Joseph Conrad performed by Da...
12. PotterCast: The Harry Potter P...
    The Leaky Cauldron
13. MuggleCast: Harry Potter pod...
    The MuggleCasters
14. The Penguin Podcast
    Penguin Books UK
15. Modern Paint Podcast
    Tate

Figure 9.45: An iTunes screen shots showing *What Can The Matter Be?* at number 1 in the specialist iTunes Arts podcast charts for the UK in May 2007.

To mark the launch of the podcast we staged a special event for 300 people in the Starr Auditorium of Tate Modern under the banner of "The Sound of Materials" in which we investigated, demonstrated and performed the art and science of the acoustic properties of materials. This event was then developed into the *What Can The Matter Be? –Live*, a demonstration led journey through some of the content featured on the podcast for an audience, once again in the Starr Auditorium, for the Tate's summer festival The Long Weekend.

Not only did the podcast reach number 56 in the national podcast charts, one place behind Terry Wogan's BBC Radio 2 breakfast show, it was also the most popular podcast in the arts category for all of May 2007. These positions have been captured in the screen shots in figures 9.44 and 9.45 . Media coverage of the project included sessions exploring some of the themes raised in the podcast on BBC Radio 4's Materials World and Radio Five Live's Anita Annad programme. The project was also covered favourably in the print media, with The Times making it podcast of the week (5th May 2007) and commenting:

> "While other art galleries go for the radio/magazine programme style in their podcasts, Tate Modern has opted for a bite-size approach with its What Can The Matter Be? series. In a collaboration with a team from the Materials Library, each brief piece explores the crisscrossing of materials, science and art in unlikely ways. Its presenters do a fine job, whether exploring fractal patterns in Jackson Pollock's works; asking whether hearing can change how you see; or explaining where that humming sound in the Turbine Hall comes from." (The Times, 05/05/2007)[11]

The impact of the *Materials Library Presents... Tate Modern* project was felt not only by the participants but the public programmes community of London. Staff from the V&A, Science Museum and Wellcome Collection attended one or more of the nights and have all since contacted and commissioned work from Materials Library. The following email from the Wellcome Trust shows the process by *Materials Library Presents* resulted in a new commission:

> "I hope you recall our conversation at one of your highly successful Materials Library nights at Tate Modern last autumn. I was incredibly impressed by the evening and by the enthusiasm and creativity of your team. Rarely have I seen an evening when the audience engages in such genuine discussion with the experts as well as with one another –and I've certainly been to plenty of events where it might have happened.
>
> I think I mentioned to you that I am running the events programme for Wellcome

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[11] This article can now be found on line at http://entertainment.timesonline.co.uk/tol/arts_and_entertainment/whats_on/article1736556.ece

> Collection, experimenting with different venues and formats just now and preparing for a spectacular opening events season." (Lisa Jamieson, Events Manager, Public Programmes, Wellcome Trust.)

The result of this communication was the Wellcome Trust commissioning Materials Library to produce *Flesh*: a hugely popular late night event for 300 people within the Wellcome Collection galleries on 9th November 2007. This was followed by *Hair* on the 14th November 2008, which 900 people attended. Two films documenting this event were made and can be viewed on both the Materials Library and Wellcome Collection websites.[12] Both films capture the hands-on nature of the events and the way in which specially devised and created Conjectures engage the audience in a variety of materials related explorations and encounters. Scans of the handouts freely available for the public at both the Flesh and Hair events can be seen in Appendix D and Appendix E of this thesis.

9.4 Concluding Remarks

In *Speed Dating Materials* and *Materials Library Presents... Tate Modern*, the role of the participating audience member was key. Both events would have failed to have happened if there had not been willing participants, and the success of each event depended heavily upon the willingness of the audience to play their part. A part that demanded a spirit of curiosity and improvisation, an eagerness to touch and to play, and an openness to discuss and question the experience presented for them.

At each of the three events presented in this chapter, conversations were enabled by the presence of the physical material. The materials were ice breaker and friend maker, the focus of debate and the spring-board for stories, and the sharing of opinion and experience. Even in the least touch-orientated event of *The Essence of Fluorescence*, the "Saturday Science Séances" sessions attracted large crowds and were reported by the Hayward events team to be extremely popular. The opportunity to not only touch samples, but do so in the presence of a designated expert, enabled people to ask questions and provoke discussion on the topic, resulting in an enhanced understanding of both the phenomena of fluorescence and the work of Dan Flavin.

The role of the supervising expert cannot be underestimated when considering the types of informed conversations that were provoked by materials. This role was most clearly exemplified

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[12] http://www.wellcomecollection.org/exhibitionsandevents/pastexhibitionsandevents/WTX041288.htm
http://www.materialslibrary.org.uk/MaterialsLibrary/events/flesh.htm
http://www.materialslibrary.org.uk/MaterialsLibrary/events/hair.htm

by the Materials Conjecturers in *Materials Library Presents... Tate Modern*, who were specifically trained and briefed on the subject of each Conjecture they were required to staff. The importance of this role was commented on by audience members and recognised by the Materials Library to such an extent that future events saw the use of some of the same Conjecturers, as well as the recruitment of new specialist Conjecturers whose profession was directly related to the content of their Conjecture. For example, three plastic surgeons and two surgical nurses were recruited to run a Conjecture in the *Flesh* event that involved members of the public learning to suture on pig skin.

The three projects discussed in this chapter typify the nature of the experimental encounters staged by Materials Library in the pubic domain. As encounters, each event demonstrates the importance of both the material-object and expert presence that work together to represent the science of the materials. For each event, knowledge gained, materials gathered and objects made feed into the wider resource of the Materials Library. In doing so, this keeps the Materials Library's material-objects culturally active; materials, samples, specimens, artefacts and objects are not simply part of an archive, but form a cast that are put on to perform, to reveal their material nature and to have meaning, prompt memory, provoke debate and generate surprise.

Chapter 10

Discussion

This chapter opens with a further examination of an object theory and an appreciation of materials in the light of the creation of the isomorphic sets of material-objects that were presented in the previous chapters. The sets of material-objects are shown to render the material-object continuum in the light of form, function and materiality, and present the resulting nexus of material-objects as a proposition for the curation of a materials library. The second section of this chapter discusses the mapping of materials in both the virtual and physical environments of some of the known materials resources. The creation of Materials Library is touched upon as an exemplar of the physical mapping of materials through considered use of the material-object continuum. The third section explores specific aspects of the material-objects in terms of their collective status as swatches and suggests a new role for the swatch within the context of materials libraries. The fourth section of this discussion examines the role of encounters in the exchange of material knowledge, with examples taken from the experiments with encounter presented in the previous chapter of this thesis. The fifth and final section of this chapter considers the 'expert' and comments on the importance of the role of an expert with the events of this thesis.

10.1 Arriving at Objects

For Graham Harman, a contemporary philosopher of metaphysics for whom everything is to be considered an object, the majority of twentieth century philosophy "contains a notable flaw"; that the inanimate world has been "left by the wayside" with the discipline of philosophy "forfeiting all comment on the realm of objects" due to its preoccupation with "linguistics turns" and explorations of human consciousness (Harman, 1999, p1). Attempting to return philosophy to a debate on objects, Harman calls for a campaign of "guerilla metaphysics" (Harman, 2002, p2), and a re-reading of Martin Heidegger's work *Being and Time* in order to form his proposed "object-oriented philosophy" (Harman, 2002). Harman's thesis of object-oriented philosophy is introduced in his 1999 paper of the same name (Harman, 1999) and explored at length in his book *Tool-Being: Heidegger and the Metaphysics of Objects* (2002). In this, Harman describes how "the tool-being of the hammer is a system made up of what formal parts it requires to function as a hammer" and states that such a system requires the presence of both the hammer as an object and the user of that object in the act of hammering (Harman, 2002, p293). This presence of the hammer as an object could in fact be considered the presence of the hammer as a *material-object*, for the functional abilities of the hammer clearly relate to the properties and behaviours of the materials from which it is made, alongside the shape into which the material is formed. The act of hammering could also be considered an instance of *encounter*, for it is the physical coming together of material-object and human action.

Such comparisons enable a reading of the material-objects created and used in the thesis, as 'tool-beings', thus suggesting a practical exploration of Harman's 'object-oriented philosophy'. The tool-being of the cubes, tuning forks, bells and spoons, are the "systems" (in the Harmanian sense) of relations between material, form and functionality. Each requires enactment, in order for the properties of their material to be fully represented (be this action a simple lift –as in the case of the tungsten and aluminium cubes, or a more formal playing –as with the tuning forks or bells) and thus draws into their system a human presence.

Further to his discussion of tool-being and the object-oriented philosophy, Harman describes the architecture of the room in which he finds himself, the organs of his body and the light illuminating the paper upon which his words are written, declaring that; "all of these objects remain loyal for the moment, performing a subterranean function with which I have no need to trouble myself, unless catastrophe strikes, and one of them fails", at which point he would be "rudely reminded of entities previously taken for granted" (Harman, 1999, p3). Another way of perceiving such "entities" would be to consider them as materials and such "subterranean functions" the atomic-, molecular- and micro- structures that effect the scientific performance and properties of the material. As was experienced with the accumulative damage of some cubes (discussed in chapter 5, section 5.3.2), or the failure of the lead bell to truly *ring* (see chapter 7, section 7.2), material properties can often be the cause of such disloyalty to the integrity and function of an object. As J.E. Gordon reminds us, if something goes wrong with an object like a boat or a bridge, an interrogation of the materials and how they were used can reveal the cause of the catastrophe (Gordon, 1976, p61-62). For Harman, "equipment is most equipment" when "it is concealed from view, as something silently relied upon" (Harman, 1999, p3). In this regard, materials are the equipment of all objects.

Despite Harman's assertion on philosophy's disregard of objects in the twentieth century, there have been notable figures who have given the subject consideration, albeit with a more 'linguistic' and 'consciousness' orientated bias (Harman, 1999, p1). In 1922, the phenomenologist Maurice Merleau-Ponty concerned himself primarily with the perception of objects and considered that "the real issue for a genetic phenomenology is how a particular size or shape takes precedence over all other apparent sizes and shapes as the size and shape of the object," to form the meaningfully experienced object (Bannan, 1967, p103). With regard to the selection of the forms of the material-objects of this thesis, such concerns of genetic phenomenology frame the selection of each material-object and the attempt to make them meaningful. The isomorphic nature of the material-objects require that a specific size and shape takes typological precedence and thus becomes the vehicle for material presentation and subsequent perception. As with each of the material-objects, the spoon was not only the vehicle for cultural meanings, connotations and associations but the means by which aspects of the science of its material could be revealed.

Merleau-Ponty asserts that "we must remember that the object is objected experiences, given to the subject not as a block but as a perspectival –'porous'– reality that takes shape from the world as it is experienced" (Bannan, 1967, p107). Similarly, encounters are experiences of specific materials and specific objects that enable the reality of the interplay between form, function and materiality to emerge from the experience of encounter and the perception of material properties. When tasting the spoons, all participants were blindfolded but there were no participants unable to perceive the form as that of a spoon. The form and applied function of the form, through the action of tasting, combined to affirm the object status of the spoon (the sense of the 'tool-being' of the spoon (Harman, 2002, p293)), whilst the material nature of each challenged the typical perception of the object in "the world as it is experienced" (Bannan, 1967, p107). The isomorphic spoons were embraced as spoon objects but simultaneously challenged their status through the shifting materiality and resultant effects. Whilst each of the spoons would clearly provide adequate functionality in physically conveying food to the mouth, some clearly fail to function due to their strong taste in the mouth (chapter 8, section 8.3).

The sets of material-objects generated through the course of this thesis, each play their part in representing the notion of the material-object continuum, as introduced in chapter 3, section 3.2 and explored through the material-object experiments of chapters 5, 6, 7 and 8. The proposition of the continuum attempts the generation of a paradigm where the concepts of materials and objects are combined in their physical actuality in the world as material-objects. Aristotle asked, "is the nature of a thing its matter or its form?" (Aristotle, 1996, p34). In the context of this discussion such a question can clearly be adapted to: is the nature of the spoon to be defined by an allegiance to a particular material or shape? Within the paradigm of the material-object continuum, the answer given to Aristotle would be that the nature of a thing is both its matter and its form for they are inextricably linked to produce the functional relation of the thing as enacted and present in the world. The role of the continuum is to provide a conceptual framework that enables the perception of this relationship between materials and objects. Each of the experimental material-object chapters attempts to render the material-object continuum by journeying from cubes, to tuning forks and bells, then finally to spoons. What becomes possible is the tracking of a single material through the nexus of emergent material-objects, revealing both the common and divergent characteristics and properties of a material, at varying scales, in varying forms, and displaying various modes of functionality.

Figure 3.2 in chapter 3.2 maps a simple nexus of material-objects in relation to the axis of material and object. The making of the cubes, tuning forks, bells and spoons rendered physical specific intersections of this diagram. The use of these material-objects in instances of encounter suggest the inclusion of a third axis of function, for the lifting, playing or tasting of each material-object is a practical exploration of the functionality of the object, as affected by the material from which it is made. Figure 10.1 serves to include this axis within a representation of the material-object nexus.

To include function in the multi-dimensional nexus of material-objects is to acknowledge the performativity of the material-object. Whether this performativity be due to innate properties or designed attributes, the functionality of the material-object is an overt form of “agency” (Knappett and Malafouris, 2008) that asks what does/can this material-object do? For example, the tuning fork has a clear function as tone generator; a functionality that can be subverted by the material from which it is made, but which demonstrates the performative values of both density and elastic modulus in the dynamic act of vibration. The tuning forks as a set of isomorphic material-objects, require playing in order to reveal the full effect of materiality on their function. In the moment of playing the tuning forks, the material-object is no longer a static snap-shot of a particular form, made out of particular stuff. Rather, the material-object becomes the site of actions that embrace the performative functionality of both matter and the possibilities of its form. Such action has at its heart the coalescence of human and non-human elements with the ‘agency’ of each party acknowledged in the instance of encounter (Latour, 1999, p180-183). The revelation of the science of the material that causes the production of different sounds (or latterly tastes) is not possible without this encounter and the performative dynamic of the material-object.

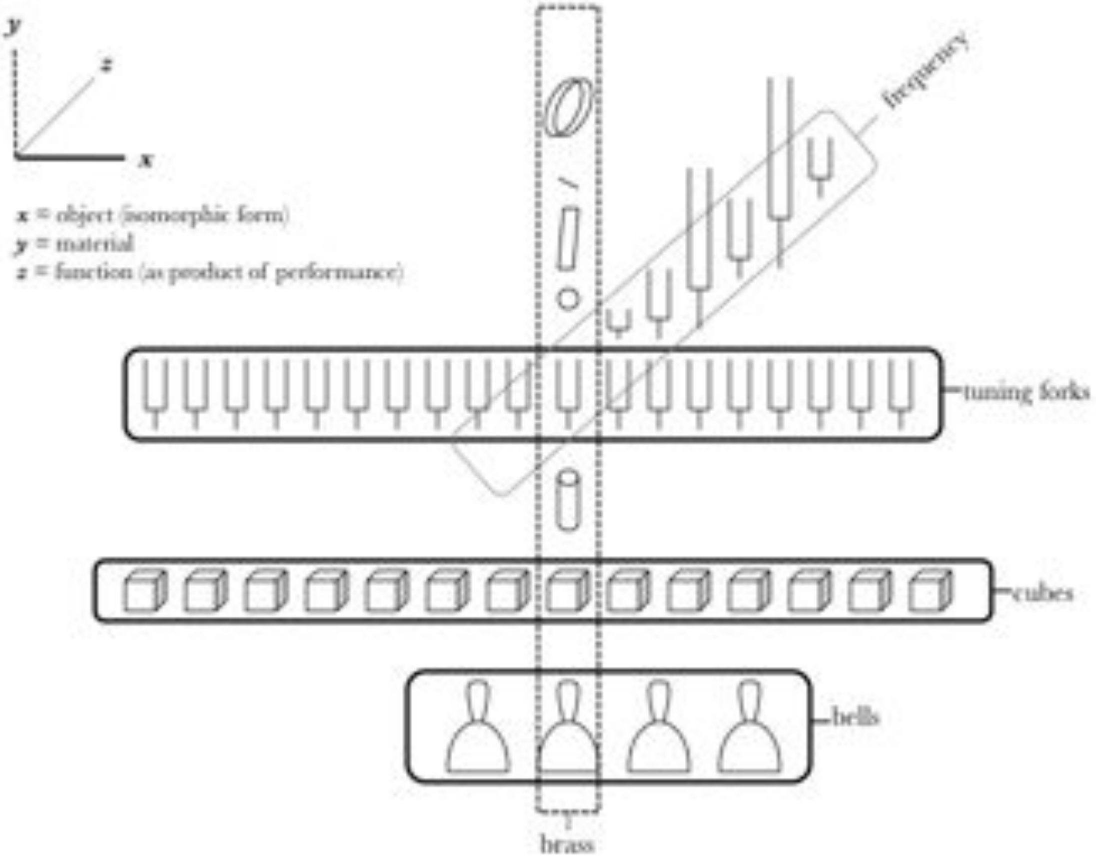

Figure 10.1: A schematic representation of the material-object nexus where isomorphic sets of cubes, tuning forks and bells keep form constant and vary the materials from which they are made. These sets are orientated on the x axis and thus display isomorphic form, and bisected along the y axis by a collection of material-objects that are each made from brass. A third set of material-objects are shown to lie along the z axis and are linked by the fact that they produce notes of the same frequency when struck, despite being non-isomorphic in form and not made from the same materials. This z axis illustrates the roles of performative functionality within the material-object nexus.

In his 1991 text *We Have Never Been Modern*, the philosopher of social science and anthropology, Bruno Latour, claims that contemporary society faces a problem when "objects count for nothing" and "they are just there to be used as the white screen on to which society projects it cinema" (Latour, 1993, p53). Such a landscape of objects is one where the consumption of the product is divorced from modes of manufacturing (Marx, 1990), and an appreciation of material. The extensive and widespread use of plastics in product design (Lefteri, 2002 & 2006), not to mention overseas production of mass consumer goods (Bramston, 2009), mean that a vast number of goods are made from plastic and simply appear upon the shelves of shops in a state of object completion and material abstraction. The wide variety of polymers available and the processes that can be employed to produce them (Ashby and Johnson, 2002) have contributed to the term plastics being used as a generic catch all for a vast number of materials, each of which can be engineered to have different characteristics. The vast majority of people however do not know the names or properties of polymers, let alone how to differentiate between them, and will use ‘plastic’ as much as an acknowledgement of a family of materials as a derogatory adjunct to describe objects perceived to be cheap, fake or poorly made (Fisher, 2004). Latour’s ‘white screen’ effect leaves the consumer playing on the surface of objects, dealing with them as ‘signs’ (Baudrillard, 2005) or units of ‘exchange-value’ (Marx, 1990), unable delve into the object and generate the sort of deep understanding of materials and their properties (Ward, 2008).

In order to counteract the ‘white screen’ perception of objects, Latour asserts that “objects are not the shapeless receptacles of social categories” but have an “agency” of their own that acts with and on each other to form an interconnected object world (Latour, 1993, p55). As Herman reiterates, “the world is a duel of tightly interlaced objects” and that “behind every apparently simple object is an infinite legion of further objects” (Harman, 2002, p296). In order for this to be revealed to society, Latour invites the reader to “rethink anew the role of objects in the construction of collectives” (Latour, 1993, p55). He calls for a “Parliament of Things” where; “[object] natures are present, but with their representatives, scientists who speak their name”, “societies are present, but with the objects that have been serving as their ballast for time immemorial” and all representatives speak of what they have collectively created; “the object-discourse-nature-society” (Latour, 1993, p144).

The material-object continuum and its consequential nexus of material-objects is a way of expressing the “tightly interlaced” and “infinite legion” of material-objects. In a Latourian sense, the creation and curation of a materials library could be regarded as the convening of a ‘Parliament of Things’. The nexus of material-objects that constitutes the collection of a materials library enables a democracy of objects to display their material characteristics.

10.2 Towards a Materials Library: The Mapping of Materials

The history of collections of objects, formally gathered together for their material interest, stretches back to the European Renaissance and on into the Enlightenment, where objects were collected in Cabinets of Curiosities (also known as Kunstkammer or Wunderkammer) that celebrated the diversity and abundance of the zoological and anthropological world (Impey and MacGregor, 1985). Such collections formed the basis of many museums, such as The British Museum in London and Oxford’s Ashmolean and Pitt Rivers Museums (Impey and MacGregor,

1985) (Bennett, 1995).

The Pitt Rivers Museum, founded in 1884, is particularly celebrated for its collection of archaeological and anthropological objects and the manner of their display that sees objects arranged in accordance of their use rather than their chronologically (Rivers, 2009). Examples of this "genetic or topological system which grouped together all objects of a similar nature, irrespective of their ethnographic groupings" (Bennett, 1995, p79) can be seen in figure 10.2. The display cabinet entitled "Methods of Making Fire" contains a collection of objects that are bound together by their common functionality. The cabinet that presents "Examples of Ivory and Antler" offers the viewer a range of objects, bound together to tell a particular material story. Aspects of this display focus on materials in a way that draws the displayed objects towards their material nature, thus rendering them material-objects. This function and material orientated mode of display physically demonstrates that "behind every apparently simple object is an infinite legion of further objects" (Harman, 2002, p296), that places them within a nexus of material-objects.

Figure 10.2: Two displays within the Pitt Rivers Museum. Left: "Methods of Making Fire" –an example of the arrangement of material-objects in accordance with their function. Right: "Examples of Ivory and Antler" –a material orientated display.

The contemporary gathering of objects for the display and revelation of their materiality is a task undertaken by many materials libraries. How such materials libraries demonstrate an appreciation of the materiality of the world through the selection of objects, is a question best answered by a closer examination of their contents and the resultant ways in which they map materials. The notion of materials mapping, for the purposes of this discussion, is to be considered in two distinct ways: first by means of the virtual environments of the database and secondly in terms of the physical environments of materials libraries.

Virtual Environments

The Cambridge Engineering Selector (CES, outlined in chapter 2, section 2.2.1) is a technical database that facilitates the "rational" selection of materials and processes for engineering applications (GrantaDesign, 2007). According to its makers, the CES allows users to "search and browse materials data, then combine it with the powerful Ashby methods" (GrantaDesign, 2009). Taking their name from their developer Michael Ashby, who demonstrates them in his many texts on material selection (Ashby and Johnson, 2002), (Ashby et al., 2007) and (Ashby, 2009), "Ashby methods" can be summarised as the production of graphical representations (what the CES refers to as "material selection charts" (GrantaDesign, 2009) and are often termed multi-dimensional scaling (MDS) maps) of material relationships that enable an efficient appraisal of materials and their relative positions to one another with regard to a specific aspect of their performance. Such charts plot Young's modulus or tensile strength against density or stiffness, for example, in an attempt to represent the materials that fall within given parameters of required performance and thus be of use to an engineer wishing to specify materials (Ashby et al., 2007).

Such plots, whilst readily understandable and meaningful to a material scientist or engineer, may not necessarily be to an artist or designer –more commonly appreciative of the physicality of materials (Ward, 2008). In Ashby and Johnson's text *Materials and Design: the Art and Science of Materials Selection in Product Design* (Ashby and Johnson, 2002), the authors apply the same methodology of material mapping to the more senso-aesthetic properties of materials. In doing so they both introduce designers to the methods of mapping materials in the sciences and bring to the subject of MDS mapping the more sensory aspects of materials.

One specific MDS map has been of particular interest in this thesis (see figure 6.1), for it plots "acoustic pitch" against "acoustic brightness" in relation to a wide range of materials to generate a map of acoustic properties (Ashby and Johnson, 2002, p.72). The isomorphic set of material-objects that are the tuning forks and bells is in effect a physical version of this MDS map, plotting the acoustic properties of materials through objects. The tuning forks and bells present for encounter their materials in a manner that enables the physical experience of their properties. The effect of the change in materials can be mapped on the MDS but *experienced* with the tuning forks and bells, thus offering a way into the science of materials for the haptically orientated materials practitioner. A materials library that embraces the isomorphic method of material-objects experimentation, in conjunction with the Ashby method of materials mapping, enables the science of materials to be represented by the materials themselves.

To measure the more subjective aspects of material properties like visual warmth, tactile softness or perceived naturalness, for example, poses many difficulties of instrumentation and perceptual comprehension (Finkelstein, 2009). The measurement of 'naturalness' is a task currently being pursued by the UK's National Physical Laboratory (Montgomery et al., 2008), under the broader banner of Measuring the Impossible[1]. The National Physical Laboratory (NPL) strives to provide objective measurements and systems for the measurement of the physical world. The fact that they are now interested in "new methods and investigative techniques for the measurement of complex phenomena that are dependent on human perception and/or interpretation" (MINET, 2009) demonstrates that there is value to be gained in measuring the more subjective and difficult aspects of the material world. As a set of material-objects, the spoons present themselves as a mechanism for the testing of the taste of materials, as shown in chapter 8. As such a mechanism, they suggest a new method and investigative technique for the measurement of materially dependent phenomena. The continuum that they plot and resulting nexus of other spoons in the world that they embrace by association, demonstrate how the science revealed by the spoons can be extrapolated. Once something can be measured it can be understood in quantifiable terms that would enable it to be rated and specified within an environment like the CES. The use of material-objects that foreground aspects of material science, for the measurement of human perception, would enable a materials library that housed such material-objects to reveal, through the nature of its collection, elements of the science of materials.

Matério, Materia and Material ConneXion (introduced in chapter 2, section 2.3.1) present digital databases for users to mine information and search for materials within given parameters of material properties. Such systems allow users to specify a material type (wood, metal, ceramic etc) and hone their search in terms of specifically desired properties of these materials. Alternatively, users can specify a range of properties and ask which materials best fit the perimeters of their search. In principle, this is a similar model to that of the CES but in practice it is far less technical, focusing attention more on providing links to physical material examples and products within their respective collections.

As shown in figure 2.9, the Materials Explorer of the Materia resource differentiates between sensorial and technical properties. Such attempts at combining technical and experiential information to form an accessible database on materials, reveal the complexities and hierarchies of systems and knowledge bases involved in appraising materials. When asking the user to specify

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[1] Measuring the Impossible is the task of a network of pan-European scientists known as the Measuring the Impossible Network (MINET) http://minet.wordpress.com/

"technical" properties, the drop-down options of the Materials Explorer require the selection of values like "good", "moderate" or "poor" resistance to UV (Materia, 2009), as apposed to a numerical expression that would indicate an operative and functional judgement. The same method is used for the "sensorial" drop-down options where properties of glossiness, texture and hardness are listed. The fact that hardness is listed as sensorial is of interest for this is one property that has been extensively measured, tested and quantified by materials science (Martin, 2002, p45-47). The options given for hardness by the Materials Explorer are "hard", "soft" or "depressible" (Materia, 2009), again demonstrating the subjective interpretations of material properties presented over and above the scientific knowledge of the property.

Whether the material properties presented by a materials library database are technical or sensorial, the information is difficult to rate in a manner that provides universally understood and predictable degrees of sensation that are meaningful to the communities who are using it, as shown by the work of both Ashby (2002, 2007 & 2009) and NPL (Montgomery et al., 2008). Strength, for example, has a well defined technical definition that can be tested and measured as a property of a material in a variety of ways (Callister, 2005), each of which can quantify and define the terms of a material's strength as tensile, compressive or shear (Gordon, 1976) and used as a value for a MDS (Ashby et al., 2007). Whilst the technical definitions and practical implications of material strength may not be known to one not versed in material science or engineering, the *experience* of material strength is. Many people use the word strength as an expression of an experience that can result from properties of toughness, rigidity, hardness and of course, strength. Thus, when faced with a non-experientially based mechanism for material interrogation –the virtual environment of the database– that which is accessed and communicated is detached from their perceived experience of strength.

The virtual environment of materials enables complex mapping systems that integrate a wide variety of information to form a database that can be useful for materials selection. Such databases have their limitations however and are not always the easiest way of communicating or revealing the science of materials in a manner meaningful to the non-scientist.

The human senses are highly attuned and sophisticated measuring tools for a vast number of non-technical material properties, be they perceptual, cultural or experimental (MINET, 2009) and (Montgomery et al., 2008). To derive understanding from doing, from making, from asking and testing with one's own senses affords learning in a fashion not supported or promoted through simple database searching. For this reason, materials are required to be present as the focus of a haptic enquiry and physical testing.

Physical Environments

Addressing our detachment from materials (Marx, 1990) and the processes by which they become objects (Harman, 2002) (Bramston, 2009), material libraries respond to a need to get "hands on" with materials (Ward, 2008). The differing collections described in chapter 2 section 2.3, do this in different ways. One of the most interesting is the Materials Resource Centre (MRC) of The Institute of Materials, Minerals and Mining (IOM3), for this collection overtly attempts to bring together the technical material communities and the design communities of London in order to "promote the transfer of materials knowledge" (MADE, 2009).

The primary mode of display within the MRC quite literally places material content behind that of the information. As described in the literature survey section 2.3.2, the entrance to each cubby hole, within which lies the material sample, is blocked by an acrylic window that displays a "description sheet" about the material within and often contains a photograph of the material it is obscuring (see figure 2.14 and 2.17 for photographic evidence). On entering the space, one is confronted with shelves lined with such description sheets; the shelves and their cubby holes are cabinets with their curiosities masked by their own information or photographic depiction. In an environment supposedly dedicated to the physical material, the immediate absence of such materials is unusual. In order to get one's hands on the material samples, one is required to use two hands to removed the information board from the front of the cubby hole.

The MRC's mise-en-scène emphasises the recorded technical aspects of material information over and above the physical material-object. The material samples selected speak of engineering and science, but their mode of display does nothing to engage the visitor in an *experience* of the science as embodied by the material. In the conference room adjacent to the area containing the shelves is a conference table, around which 16 chairs are arranged for visitors to sit on at the table (this arrangement is visible in the left hand image of figure 2.18). Behind these chairs, obscured slightly from view in figure 2.18, are three car seats, a Tom Dixon polystyrene chair and a wheelchair. If this scenario were to be considered through the lens of the material-object continuum as a tool for materials library curatorship, a real opportunity for material-object investigation, interrogation and exploration presents itself. The function of the chairs around the conference table is a constant; all 16 are there to be occupied. There is no reason however, why each of these chairs could not be made from different materials and explore the multitude of forms that constitute chairs, providing a 'swatch' of chairs for the use of visitors. To treat all the chairs in the room as a swatch of material-objects would no longer see some chairs relegated to the sidelines to look on whilst others were being used. To have one person sat in a wheelchair, another on an inflatable chair designed for use in swimming pools and a third on a oak dining chair would provide users of the conference table with a experience of materials in relation to the function, through the appreciation of their effect on object, not just a venue for discussing materials. Such an approach would therefore enable the science of materials that affected the function of different chairs to be demonstrated.

The science of materials is represented within the MRC primarily through the content of the data sheets that describe properties, uses and behaviours of the materials, and the genre of the samples present, which tend to be the product of material industries represented by the IOM3 (Bellara, 2009). The model presented is similar in objectives to the CES; considering the material selection needs of the user in relation to material engineering and manufacturing possibilities. Visitors can come across “strain-rate dependant rubber”, “extruded aluminium beams” and “rotationally moulded polycarbonate packaging” –descriptions that use technical terminology that enforces the relationship between the material and its processed form and presence as an object of engineering.

Although many of the materials samples are strongly orientated towards the products of industry, manufacture and high-end material performance, the majority are off-the-shelf “components” (Bellara, 2009) which can be sourced, specified and purchased. The teflon saucepan, the carbon fibre tennis racket and the polyurethane frisbee are just such examples. Whilst each of these objects is interesting, they are not presented in comparison to any other object that is either made from the same material or designed to perform a similar function. The world of “interconnectedness” (Latour, 1993) is little represented, let alone the “duel of tightly interlaced objects” (Harman, 2002, p296). To simply orientate the collection towards “components” does not celebrate the art, craft or design, let alone usher in the cultural, historical, anthropological, archaeological or topological aspects of materials. A consideration of such things may lead the teflon saucepan to be allied with a traditional copper pan which in turn might connect to a copper IUD (intrauterine device), some copper shim and a copper spoon within a material-object nexus.

In the entrance hall of IOM3 is an installation by designer Chris Lefteri entitled *Materials Family Tree* (2006). The display is not formally part of the MRC but does demonstrate an approach to objects within the context of IOM3 and is, in some respects, a form of materials library, for it endeavours to generate a materials-orientated physical environment that foregrounds the materiality of things. Author of many books on materials for product design (see Literature Survey, Chapter 2.2.2), Lefteri’s installation has an object-centric approach and attempts to render the connections between objects through reference to common processes and properties. The central photograph of figure 10.3 shows the installation and the presence of a tennis racket similar to the one found in the MRC. This time the tennis racket is contextualised by the inclusion of samples of all its constituent material parts, arranged around it. Two other objects from within the *Materials Family Tree* are seen in figure 10.3. To the left, a porcelain cup and to the right a pressed glass lemon squeezer. The porcelain cup has a styrene handle and is presented to demonstrate how "adhesives with the right degree of flexibility have made previously unthinkable combinations of ceramics and other materials possible"[2]. Such an object is both familiar in its form and function and unusual its materiality, serving to represent the possibilities of processes and material combinations. It is of course a pity that none of the items can be used for it would not be until drinking a hot drink from this cup that one would appreciate the advantages of a less thermally conductive material being used for a handle.

Figure 10.3: Chris Lefteri's installation *Materials Family Tree*, located in the entrance hall of The Institute of Materials, Minerals and Mining, London. Although not strictly part of the MRC it clearly celebrates the place of materials in the design of objects. Left: A porcelain cup with a styrene handle. Centre: An overview of the *Materials Family Tree* installation. Right: A pressed glass lemon squeezer.

The *Materials Family Tree* not withstanding, the MRC presents its material space as if it were an illustrated version of a technical text book. The physical samples are contained within, and bound by, the information that has been deemed interesting, relevant and in some way useful enough to be given on the "description sheets". Although far less extreme in their scenographic presentation of written material information, other materials libraries also present such information in close proximity to the material itself, often physically linking material and information by means of a chain or sticker (as shown in figure 2.19 and outlined in Chapter 2, section 2.3). Even Lefteri in his *Materials Family Tree*, uses labels to describe the contents of the collection in terms of their materials, properties and processes, albeit that the labels are printed on tracing paper and mounted on acrylic to provide, through transparency, a minimal

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[2] Text taken from the descriptive label printed on tracing paper and mounted on acrylic within the *Materials Family Tree* installation.

intrusion.

The rationale for the use of any label within the context of a materials library is clear; to communicate information such as the material's identification, who makes it, and what it does. It makes sense to use such labels when a user of the resource is alone in their exploration of the materials. It also makes sense to keep the information given concise, coherent, and broadly informative. It is easy to physically attach labels when the material samples adhere to the trope of the classical swatch, for there may already be a chain in place upon which a label can be hung, or an under-surface to which a label can be stuck that does not damage the integrity of the material or inhibit an appraisal of the material's finish. It is also easy to do when there is little cultural information or conceptual explanation required to form an understanding or appreciation of the material. The samples within the materials collection of Material Lab, as shown in figure 2.10, are physically and conceptually suited to being labelled, as shown in figure 2.11. All the samples present themselves with a front, the displayed surface of the tile, and a back, where a label can be unobtrusively located. The information communicated on the label is factual and targeted at those people looking to procure the tiles for a specific function. The labels work because the qualities that can be known and measured are recorded on the label whilst leaving that aspect of the sample that cannot be measured free for the individual to perceive and appraise for themselves.

As has been seen with attempts at the digital archiving of information in the form of materials library databases (see chapter 2.3), much that is deemed interesting may be difficult to define or record in a concise manner on a label, let alone definitively measure. Until an ability to measure what MINET would describe as "the impossible" has been achieved, –"for to do so is probably not impossible, simply very difficult" (Finkelstein, 2009)– the objective measurement systems that are applied to the material world do not describe many of the properties of materials that one encounters within a material library. Therefore, the contents of labels and databases that rely so strongly upon the notion of containing definitive objective information, will only portray a small part of the story of a material. In order to generate a system for the delivery of material information that embraces cultural narratives and objective and subjective data, let alone material demonstration and processes, an information resource would need to be a masterful multi-media integration of a vast array of sophisticated knowledge sets, many of which do not yet exist.

In making the Materials Library, I decided not to make a searchable database or digital interface for visitors, and to have the most discreet labels possible that simply ascribed a number to the material-object. It was intended to be a materials library that investigated the primacy of materials, people, and their interaction (material to material, people to material and people to people) where information was exchanged through experience and discussion rather than reading. I wanted people to enter the space and be immediately presented, surrounded, confronted and embraced by materials in a way that would invite curiosity, wonder and intrigue about the *stuff* itself, promoting physical exploration and the asking of questions. To wander round reading labels, checking items off a list or hunting in an index is a mode of operation that I was keen to reject in favour of the generation of experiences that placed the physical encountering of materials at its heart and, in the devising of both material-objects and encounters, acknowledge the scientific and cultural aspects of materials. In essence, the Materials Library focuses on the physical mapping of materials by rendering physical a nexus of material-objects through their collection, making and presentation for encounter, in a manner that enables the experiential exploration of the science of materials.

The material-objects made during the course of this thesis were designed to communicate aspects of the relationship of form and function to materiality. The experiments presented have shown that such an approach to materials library curatorship can be taken in a way that embraces rigour, technical information and scientific content. The tuning forks and the bells are sets of material-objects that utilise the isomorphic methodology, operate as both instruments for the scientific demonstration of the effect of density and elastic modulus on sound, as well as more obvious instruments for the generation of musical tones. The spoons demonstrate that the material-object can also be the tool for the formal scientific investigation, as well as perceptual revelation through experience, of the scientific properties of materials.

The Materials Library events that have been staged over the course of this thesis can been viewed as discrete exercises in the role and making of materials libraries. Each time, a nexus of possible material-objects is imagined around a given thematic (be this as broad as ‘material delight’ or as specific as ‘fluorescence’) and rendered through the collecting, making, display, demonstration and encounter of those material-objects finally presented.

This is best exemplified by a number of the Conjectures within the *Materials Library Presents... Tate Modern* event. The Black & White Tables Conjecture (see section 9.3.1 and figure 9.34) presented within the Idea and Objects gallery, and The Table of Improbable Objects (see section 9.3.1) located within the Poetry and Dream gallery space, are both examples of specific organising principles creating displays that explore material taxonomies and reveal new connections between materials, objects, form and functionality. The titles of each conjecture give away something of the nature of the items to be found on each respective table. The Black & White conjecture presented material-objects of any form, material or function but only if they were either black or white in colour, whilst the Improbable Objects conjecture presented material-objects of wonder, confusion, bafflement and delight that through their material nature transformed the object into something ‘improbable’. In both cases of conjecture, the organising principle and concept came first, instigating a process of, and exercise in, materials taxonomy. In the Materials Cubes Conjecture (see section 9.3.1) in the Material Gesture gallery, a similar impetus saw the use of all the 4cm^3 cubes of chapter 5, in an attempt to explore and experience through isomorphic material-objects, relative densities of materials and the fundamental property of matter that is Mass. This conjecture was reconfigured and developed through the course of the four Acts of the *Materials Library Presents Tate Modern* event, culminating in their use as the abstract tools for the exploration of taxonomy in the Exercises in Taxonomy and Relocation Conjecture (see section 9.3.1). The question was asked; how can these cubes be categorised? Paving the way for discussion on and physical attempts at material categorisation and taxonomy, the audience were required, in essence, to map material space and produce a nexus of meaning based upon perceived similarities and differences.

The overarching aim of all the Conjectures was to provide a range of material-objects for encounter that communicated something about their material properties without the need for written explanation, an idea that will be explored later in section 10.4. The events provided evidence of how the material-object continuum and the development of a conceptual nexus, enables the framing of taxonomies and generation of content that explore the multiplicity of materials in relation to their form, function, performance and perception. In doing so, the events formed part of a methodology for the creation of a materials library that acts as a palette for, and recipient of, content that can be repeatedly staged for encounter.

10.3 Going Beyond the Swatch

In chapter 3, Approaching Objects, I outlined the role and trope of the classic material swatch (see section 3.3) and asked if it were possible to create other types of swatches that bought specific structural phenomena and materials behaviours to the attention of the user. Chapters 5, 6 and 7 explored the making and use of three sets of material-objects; cubes, tuning forks and bells, in an attempt to demonstrate structural phenomena and materials behaviours. Using an isomorphic methodology, the objects selected traversed the material-object continuum and enabled the experience of each material-object to be mediated by the material from which it was made.

As a set, the cubes demonstrated the density of a range of materials as an expression of their mass in the set unit volume of 4cm cubed, thus demonstrating the concept of weight through the experience of lifting the material-objects. The number of cubes made could have been greater, thus creating an even more expansive swatch, but the limits of time, material availability and manufacturing processes played their part, along with the decision that there was a sufficient range of materials presented to begin an appraisal of similarities, differences and extremes. The form itself proved small enough to be held in the hand but large enough to provide a mass of clearer experiential potential. The corners led people to an appreciation of varying hardnesses and the subtle role of damage to reveal material properties as certain cubes were found to change over time under repeated handling. The importance of physically handling the cubes was however, paramount to their encountering and thus the appreciation of them as material-objects.

As a set, the cubes presented no explicit object functionality, making them the most classical 'swatch' of the thesis. The tuning forks and bells, on the other hand, were forms that provided clear and specific object functionalities. Although these functions were understood through the recognition of the shape of the material-objects, the functions were simply conceptual: both the tuning forks and the bells required playing. In the same way as the property of the mass of a cube was not fully appreciated until the cube was held, the effect of the change in materials on the sound of the tuning forks and bells was impossible to appreciate without the experience of the sound. The sets of tuning forks and bells, through both the meaning of the object and the role of the material from which they were made, are highly performative. It is required that they are used and it is not until they are, that the full effect of their materiality is experienced. The material performs in order to create a specific effect that is enabled through the performative intervention of the user. Thus, the representation of the science of materials is more fully possible when the performativity is embraced by the material-object. It is at this point that material-objects "rethink anew the role of objects in the construction of collectives" (Latour, 1993, 55) and present themselves as an über-functional swatch, able to embrace the cultural and scientific aspects of materials.

The making of swatches that go beyond the standard representation of materials, towards a set of material-objects that are required to be *used* and in their use, reveal materials science, has been a key aspect of the work of this thesis. The very act of engaging in, and with, processes of making, revealed material properties and behaviours that were due to science of the material, as evidenced by the shrinking wax cube of chapter 5, section 5.2.3. In designing, making and using the material-objects of this thesis, specific aspects of material science were shown in relation to the real world experience of them. The subjects that each material-object was designed to represent were primarily linked to the properties: mass, density, elastic modulus, co-efficient of loss, electrode potential and other chemical properties. The microstructures and behaviours of materials that produce each of these properties were rendered macro through the creation of material-objects that presented the properties as experience. Such rendering and the resultant experiential discovery of objective scientific principles through the use of objects themselves, has been a key way in which the trope of the swatch has been explored in an attempt to communicate deeply about the nature of material-objects.

Undertaking such a task of making, as a way of generating content for a materials library and investigating the varied properties of materials, is also unique to the work of this thesis. The only other library outlined in the literature survey that has an overt relationship to the making of their material content is Material Lab (see chapter 2, section 2.3.1). The tiles that line the walls of Material Lab have been made and are sold by the founders and funders of the collection. Material Lab's status as an enormous swatch is clear (through the presentation of samples of uniformed dimensions, see figure 2.10) but the forms of the material-objects within this swatch are not designed for the communication of any micro property of the material. The science of the material and the processes by which it is formed are not communicated (and in some cases are probably industrial secrets). Variations in glazes are presented as predominantly aesthetic, occasionally functional, with tiles available in a rainbow of colours for a range of applications. All samples are presented in Material Lab as perfect, and rightly so, for they are trying to sell them as functional and aesthetic objects, but in presenting such perfection, the workings of the material go unacknowledged. The tiles and their display are not designed to highlight faults of failures that would highlight process and techniques of production, demonstrate the limitations of the material and a enable broader appreciation of the tile's materiality in a manner similar to that achieved by the damaged cubes (see section 5.3.2 for the discussion on damage). In making swatches of unique material-objects that embrace failure, difference and loss of functionality, materials as the equipment of objects, are no longer required to be "concealed from view, as something silently relied upon" (Harman, 1999, p3) but can express their "agency" and role to play in the world of objects.

Materials Lab is also a prime example of the power of the swatch in a commercial sense and the role as a commodity. The material-objects conceived of in this thesis are not for sale, nor are they trying to sell you something. Material-objects reconnect people and materials in a way that returns sensibility and sociability to material forms, establishing that which Marx claimed to be lost when the efforts of labour are commodified; the "material relations between persons and social relations between things" (Marx, 1990, p166). The swatches of this project attempt to return sensibility and sociability to materials' forms, as will be discussed further in section 10.4. With regard to going beyond the classical swatch, a de-commodification of materials and objects, through the establishment of each as a material-object, asks what it means to be a material and object with properties, use and function outside of a commercially valued system. The swatch, once released from commercial baggage, is free to explore the science, culture, art, craft or design of *stuff*. The reason for its making does not need to be commercial but can be for the communication of materials knowledge, experience and understanding, through haptic modes of investigation.

Whether it be commercial or not, a swatch provides a specific type of functionality, a functionality that could be said to relate to an "ability to become integrated into an overall scheme" (Baudrillard, 2005, p67) –a scheme of a materials library. If swatches are designed to explore and reveal the performative properties of a material and illicit performative engagement from the user, the recognition of meanings and significance that belong to material-objects as active agents within the material world, are also integrated into the scheme of a materials library. To embrace functionality within the swatch clearly brings the performative dynamic of materials to bear on the terrain of a materials library. Such a point of view requires a time-based theoretical framework; one of scenographic performance studies where a materials library becomes a stage for the presentation and activation of form, in space, over time. A swatch upon such a stage can be regarded as four dimensional, having both the three dimensions of space and the fourth of time.

Changing the methodologies of swatch creation changes the methodologies for a materials library. A swatch can be considered as a synecdoche for materials library, a part that stands for the whole. The sorts of relationships materials libraries form with swatches is indicative of how they treat the whole of their material map. To apply a material-object treatment as a de-commodifying statement of material intent, enables the creation of a materials library, and the swatches that reside within it, in a fashion that embraces materials for all their abilities, functions and uses, as well as their failures, inadequacies and mysteries. To exploit, explore and present the cultural aspects of materials alongside the formal and scientific, in a manner that promotes the physical exploration and encounter of each, enables a fuller picture of what a material might be to be presented within the context of a materials library.

10.4 Exchange, Knowledge and Encounter

In his 1641 text *Meditations on First Philosophy*, René Descartes wrote the following rumination on his encountering the transformations of wax.

> "Take for example this piece of wax; it is quite fresh, having been but recently taken from the beehive; it has not yet lost the sweetness of the honey it contained; it still retains somewhat of the odour of the flowers from which it was gathered; its colour, figure, size, are apparent (to the sight); it is hard, cold, easily handled; and sounds when struck upon with the finger. But, while I am speaking, let it be placed near the fire. What remained of the taste exhales, the smell evaporates, the colour changes, its figure is destroyed, its size increases, it becomes liquid, it grows hot, it can hardly be handled, and, although struck upon, it emits no sound." (Descartes, 1901, p17)

Such an account eloquently highlights the importance of physical encounter in forming an appreciation of material properties, characteristics and behaviours. His observations champion haptic explorations and suggest he would be at home in the kind of materials library where smelling, tasting, touching and listening to materials were all encouraged.

Over the course of this thesis multiple instances of encounter have been staged that present material-objects for the exchange of knowledge in an attempt to return sensibility and sociability to materials. Each of these encounters, be they within the context of formal events such as *Materials Library Presents Tate Modern*, or less formally between visitors to the Materials Library and the individual cubes, are relation acts in a Bourriaudian sense; acts that engender modes of sociability between persons and material-objects. The events are "moments of sociability" that contain "objects producing sociability" (Bourriaud, 2002, p33), and as such, explore the "material relations between persons and social relations between things" (Marx, 1990, p166).

The *Materials Conjectures* discussed in chapter 9.3 were stations for encounter where material-objects were gathered together and spoke to one another, where people gathered and were prompted to speak to one another about/because of the material-objects, and where the opportunity for physical interactivity was provided. Within these materials conjectures, the 'moments of sociability' were numerous and widespread, multifaceted and various; the material-objects were highly 'sociable' and engaged in multiple encounters and visitors engaged with each other as a collective. Material relations were forged between material-objects both in and out of the designed conjectures as a result of the encounters people had with them and the knowledge gained from them.

During the course of the evening within the Material Gestures gallery (see section 9.3.1) the thermochromic pigments impregnated into the sugar paper of the Thermochromic Snail (see section 9.3.1) formed a relationship with the sodium acetate hand warmers of the Liquid Pillows (see section 9.3.1) and change colour. The interaction between the two materials produced a tangible transformation, demonstrating the ability of materials to effect each other and the role of environmental conditions on the performance of a material. The bringing together of the two materials was done by an audience member who had, after experiencing the properties of each material separately, seen a relationship between two that stemmed from the production of heat by one and need for heat in the other (as outlined in section 9.3.2; "Thermochromic Snail meets Liquid Pillows"). The audience member's assimilation of knowledge is demonstrated by their actions, providing tangible evidence of the role of physical encounter in the communication and expression of material information and knowledge.

Such evidence was seen time and again throughout the *Materials Library Presents Tate Modern* event, be this through the improvised combination of conjectures by audience members or the unexpected activities within the conjectures themselves. The extrusion of the silly putty throughout the Poetry and Dream gallery space for example (as seen in figure 9.35), overtly demonstrated an impetus of audience members to literally push and pull the material-objects presented for encounter, testing the limits of the material-object and the extent to which they can get to know the material. Such co-oporative manipulation and haptic interrogation demonstrates that people were engaging with "material relations between persons and social relations between things" (Marx, 1990, p166) –rediscovering the potential sensibility of materials.

The encounters outlined in this thesis show that in order to appreciate the 'sensibility' of a material, one must be allowed to touch, manipulate and even break the material-object. An environment that enables the coming together of materials and people for the making of an encounter, be this environment a materials library or staged Conjectures, must be a place where haptic exploration is encouraged and thus understood as a primary tool for material interrogation. The tool need not always be the body; in the case of The Non-Newtonian Trough Conjecture (see section 9.3.1), the tool for materials interrogation was a hammer. Whether the tool be applied directly or indirectly to the material under interrogation, the act of the coming together of the tool and material reveals information about specific material properties to the user. The staggering ease with which the wafer of aluminium nitride cuts into a cube of ice using only the heat conducted by the user's hand (as presented on The Table of Improbably Objects, see section 9.3.1) shows that both material and tool are material-objects that can illicit material and conceptual transformations. It is not until the experience of this ceramic wafer, gliding into the ice as easily as if it it were butter, is felt that one can begin to understand it and measure it against other experiences of ceramics, ice and cutting into a solid material.

Evidence for the revelation and exchange of knowledge through material encounters was also seen in the *Speed Dating Materials* workshops, outlined in section 9.1. These encounters further portray a return to the sociability and sensibility of materials, with participants engaging in processes of sensorial investigation that were both physically and verbally evident, revealing the way in which participants attempted to gain an understanding of the material through the experience of it. Participants repeatedly used words like "heavy", "smooth" or "shiny" to describe their perception of the materials in a manner that used a range of senses to evaluate some objective property of that with which they were presented. Objective appraisals were often followed by attempts at categorisation, some more successful than others, with participants making statements like "I think it's a rock, or a crystal, or some sort of metal", "this is amber" or "I think it's rubber". Just as common as attempts at material identification was the interrogation of the material-object in terms of its use value where declarations of ignorance or assured recognition could be heard;"I don't know what it's used for", "it's a little shovel for eating ice cream".

Such attempts at objective appraisal and identification are to be expected, for they are the subject areas materials libraries typically address through their remit of providing information on material origin, specification, applied use and product status. There are, however, other aspects of the participants' responses that reveal broader systems of material knowledge and demonstrate the wider subjective material appreciation that can be obtained through such encounters. Such responses typically revolve around association, action and opinion.

Examples of comments that reveal the associative powers of materials range from "it's like having a fly's eye" (in response to looking through the honeycomb aluminium) to "it is like one of those things that go down stairs... a slinky" (in response to the non ridged honeycomb aluminium) and "this would make a very thick window. I wonder if it is the sort of glass used in massive aquariums" (in response to tile of floated glass). Such associations often draw upon the cultural and historical aspects of materials. The following extract clearly demonstrates the associative journey the participant went on when encountering the live-edge acrylic ice cream spoon, visible in figure 9.3. The participant opens with statements of the recognition and identification of the object and its use, revealing their prior experience of such an item in the world at large. They then go on to imagine other uses and critique these in the light of an understanding of the material's strength.

> "I know what this is. It's a little shovel for eating ice cream. I guess you could eat

> other things with it but you wouldn't get very much up at a time. It would be funny to try and eat properly with it, perhaps with one of the wooden fish and chip forks you can get. It's like a little spade. You could try digging with it but it's probably not strong enough to cut through much."

The same participant then proceeds to examine the piece of amber and spies inside "some sort of insect, like in Jurassic Park", before following a similar trajectory of associative thinking based on the cultural resonances of the material. They then reveal that they "used to have an amber necklace but it was much darker in colour than this" before questioning their previous assessment that "this is amber" stating, "it's smooth and plastic like. Actually, it could be a fake, I suppose. I wouldn't know how to tell". At this point the participant lifted the amber to their lips and gently taped it against their teeth. Through a combination of sensory perceptions, prior material knowledge and comprehension of it's cultural status as something people do fake, the participant produces a specific physical action in attempt to test the material.

Many of the actions performed by participants in response to the materials encountered reveal how participants used their bodies to interrogate the materials. Examples include the repeated bending back and forth of a material in an attempt to fatigue it, scratching into a material with a finger nail to test hardness and squeezing a sample in various directions to test the compressive strength. Other actions were more playful and ranged from strumming the side of the object as if it were a guitar to a participant going so far as to stand up and move away from the table before bouncing the material onto the floor. Despite being more playful, these actions revealed to participants how the material responds to specific actions and moments of enactment. This can be shown by the commentary of participants when engaging in such acts of play; "I was not expecting that", " I just want to keep it moving" and "I expected that".

Statements along the lines of "wow, that's surprising", "I like this" and "I would enjoy spending more time with it" are verbal demonstrations of the opinions formed by participants with qualitative judgements ranging from "it's comforting somehow, companionable, friendly" and "seems more special to me", to "errr, I don't much care for it". Such comments serve to underline the subjective nature of materials experience whilst also demonstrating that given half the chance people are well equipped to exchange their knowledge of a material, especially when they are able to test their knowledge through the physical experience of a material.

The *Speed Dating Materials* workshop underlines the importance of the presence of material-objects as the kernel and agitator for the discussion, demonstration and exchange of material knowledge between participants with differing materials backgrounds. Lorraine Daston, a historian of science with a particular interest in the significance of objects that are shared by differing communities, claims that; “without things, we would stop talking” (Daston, 2004, p9). Such an assertion invites the summation that “with things, we talk” –a sentiment demonstrated throughout the material encounters described in this thesis.

Within the scenario of a staged encounter, the material-object acts as a *boundary object* (Star and Griesemer, 1989), that crosses the borders of material disciplines and operates for multiple communities simultaneously. As has been mentioned previously, the tuning forks in particular are simultaneously equipment for scientific demonstration and an object of musical expression. They are a set of material-objects that provide an experience of the sound of materials but can also enable discussion on the technical reasons for this experience. Such material-objects are, in effect, what Star and Griesemer would term *ideal type* boundary objects; specimens “which incorporated both concrete and theoretical data and which served as a means of communicating across worlds” (Star and Griesemer, 1989, p410). Material-objects, as ideal type boundary objects, rely upon the physical coming together of people with materials to serve as such means of communication. The presence of the material-object is the focus of attention and a springboard for discussion; the mediating agency that enables the exchange of knowledge and the receipt of experience through the vehicle of encounter.

10.5 The Expert

Two hundred years after Descartes’ meditation on wax, Michael Faraday was also to be found thinking deeply on this material. He gave a series of lectures entitled *The Chemical History of a Candle* that used the candle as a material-object for the revelation, communication and demonstration of the physics and chemistry of combustion (Faraday, 1861). The lectures were turned into a book in 1861 and remain available to this day, but what is striking about the text in terms of this thesis is that it is a record of an expert delivering materially orientated content to an audience of non-experts. Faraday’s position as a fellow of the Royal Society and Fullerian Professor of Chemistry at the Royal Institution of Great Britain made him extremely well qualified to speak on behalf of the candle. As a physicist and chemist he was not just a theorist but an experimentalist, meaning he was equipped with the practical skills and knowledge of his material acquired through a practice of ‘doing’.

The success of “How To” videos on YouTube (Cha et al., 2007) exemplifies a popular desire to have forms of ‘doing’ demonstrated. From guitar lessons and make-up tips to demonstrations of wood-turning and the breaking of a wine glass with sound, the internet offers many people access to demonstrated expertise in skills, crafts or material-related phenomena. For sociologist Richard Sennett, to have expertise and experience, in the sense of knowledge gained through previous and repeated encounter or the acquisition of skill, is to be a craftsman (Sennett, 2008, p288-290). The expert craftsman comes for Sennett in “two guises; sociable or antisocial” (Sennett, 2008, p246). It is the social aspects of the craftsman that most concern this thesis for “the sociable side of the expert addresses the issue of knowledge transfer” (Sennett, 2008, p248).

Be it within the context of the Materials Library space or a Materials Library event within a gallery, the role of the expert in designing, staging, executing and participating in material encounters is crucial to the success of the encounter. No matter how well designed a material-object or swatch of material-objects, the experience of them can often be improved by the presence of an informed, engaging and “sociable” expert.

When encountering material-objects, people often look to an expert figure to affirm theories, ask questions and exchange narratives. As was seen in the *Speed Dating Materials* workshops, participants would occasionally defer to the expert hosting the workshop to seek permission to act in specific ways or confirm their ideas about a material (see section 9.1.2). Such acts of deference illustrate that not only do many perceive their materials knowledge as incomplete but that they also wish to make fuller sense of that which they are experiencing, to have their curiosity rewarded and their understanding enhanced.

The Essence of Fluorescence cabinets of fluorescent curiosities were displayed over the course of three months at the Hayward Gallery without the presence of an expert, except at the designated times of the Saturday Science Séances (see section 9.2). The large number of visitors who attended the Séances demonstrated that there was an appetite amongst members of the public to hear from, and engage with, an expert on the topic of fluorescence and the contents of the cabinets. This desire was underlined by the observed behaviour of many visitors throughout the exhibition. On such occasions, when no official expert was present, the desire of people to share experience and knowledge about the materials was revealed through their conversations and actions. One man was recorded as saying to his partner; “look, objects under UV. I’ve got a UV light at home. It would be good to go round and see what fluoresces”. She replied “look! teeth” to which he responded “yes, I know about that one. It’s calcium in the water”. Whilst revealing some degree of identification ability, the man was keen to display some form of greater understanding of the subject, to display a little technical knowledge and relate that which he was seeing to a wider sphere. The fact that the information he was sharing with regard to why he thought the teeth fluoresced was incorrect is of less importance than the fact that whether correct or not, he was willing to share information and attempt take the role of expert within the exchange.

After the success of the Saturday Science Séances and the lessons of *The Essence of Fluorescence* installation it was clear that for *Materials Library Presents Tate Modern*, a more overt expert presence was needed. It was important that the event was not a lecture and both the setting and format ensured this, but it was understood that there would need to be some form of expert facilitation alongside the installed material-objects. To this end the role of the Conjecturer was conceived (see chapter 9, section 9.3.1). The eight people who were employed in this role did receive training and had backgrounds relevant to a broad spectrum of materials, but were rarely fully immersed in a professional sense in the exact topic of their material conjectures. Their role was often one of encouraging interaction, answering questions and supporting the needs of the material-objects. In some instances of encounter and conjecture, the material-objects serve as props to the conjecturer in a manner akin to the props of a conjurer; used to reveal and conceal the tricks and talents of the material-object and direct, delight and dazzle the audience.

When it came to devising and staging the *Flesh* (2007) and *Hair* (2008) events at the Wellcome Collection, the desire to increase the expert status of the conjecturers lead to the formal engagement of a range of material experts. Each expert was hand picked to perform specific tasks, supervise specific activities that related to their material practices and share their knowledge with the inquisitive public within the context of a framed conjecture. Three plastic surgeons and two surgical nurses were used to run a ‘flesh as material’ conjecture where members of the public could first cut, then sew back together, a section of pig’s skin under the supervision and tutelage of a surgeon or nurse. Other experts employed for *Flesh* ranged from the British heavyweight bodybuilding champion (expert in the building of specific forms of flesh) to a life drawing tutor for a series of life drawing classes that explored representations of flesh and human anatomy. The same approach was adopted for the *Hair* event where master wig makers, beauticians and barbers were present alongside biologists, chemists, psychologists and cultural commentators who joined the public in a celebration, interrogated and hands-on exploration of the materiality of hair. Each of the experts used in *Flesh* and *Hair* were expert material practitioners in the mould of Sennett’s sociable expert; able to “address other people in their unfolding prospects just as the artisan explores material change”, their skills exercised as mentor in a manner comprehensible to non-experts (Sennett, 2008, p251).[3]

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[3] Video documenting both Flesh and Hair events were made and show many of the expert practitioners in action. Both videos are available to view on-line via the Materials Library website: www.materiallibrary.org.uk and Materials Library YouTube channel: www.youtube.com/user/MaterialsLibrary

The role of the expert conjecturer within a Materials Library event is also akin to that of Bourillard's interlocutor within the artistic event; always in a position of knowledge, thus able to draw together the art (or in the case of the Materials Library, the material-object) and the public. Like the interlocutor, the expert conjecturer is often in a position of greater knowledge, be this scientific, cultural or experiential, thus enabling them to share this with audience members through the process of encounter.

Within the chapters of material-object experimentation (chapters 5, 6, and 7) the role of the librarian was considered as threefold. Firstly the librarian was the host, facilitating and staging encounters and with specific sets of material-objects. The second role was that of the participating action researcher, the observer who witnesses and then assimilated that which was observed to inform future efforts of staging. The third role was that of the embodiment of materials knowledge; being the person to whom questions could be asked and who was able to make connections between items within the collection. In other words, the über expert conjecturer. Not simply the expert who knows the most (for they may not), but the person who ties the threads of knowledge together and sews them into the tapestry of the materials library.

Whatever form the expert takes, it is paramount that within the context of the Materials Library, this person is able to make connections between materials, processes structures and properties; reveal technical knowledge, cultural histories and experiential possibilities; devise and create material-objects that map the nexus of material-objects in a way that generates surprise, delight, interest and understanding.

Chapter 11

Conclusions

1 The material-object continuum as a curatorial tool for the creation and curation of a materials library.

The idea of a material-object continuum is a useful framework for the curation and creation of a materials library for it offers a nexus of possibilities that provide a way of perceiving similarities, differences and linkages between material-objects in relation to their form, function and materiality. The single axis of material and object provide the terrain for isomorphic exploration whilst the broader nexus of collective material-objects, that constitute a materials library, affords exploration of material-objects along the axis of functional, perceptual, cultural or scientific performance. Through mapping and generating material-objects that render physical plots on a material-object continuum, a collective of multiple taxonomies becomes possible. Such taxonomies were explored in this thesis through the curation of events and specific instances of conjecture.

2 Going beyond the swatch.

The presence of the swatch in the majority of materials libraries has shown to be central to their material display and part of the mechanisms of haptically based materials selection. The swatch is a synecdoche for a materials library, a part that stands for the whole, a member of the collective whilst simultaneously being a collective. This thesis has attempted to go beyond the standard trope of the swatch; to push, tweak, negotiate and pervert that which constitutes a swatch through the development and exploration of the isomorphic methodology. Sets of material-objects were made and used within the Materials Library and at events to explore specific aspects of materials science and its relationship to form and function of objects.

3 Materials provoke the exchange of knowledge.

The importance of material encounter as the basis for the exchange of knowledge has been central to the work of this thesis for it recognises the potential for the physical coming together of people with materials to provoke an exchange of knowledge. The presence of the material acts as the focus of attention and a spring board for discussion, the mediating agency that acts as the thing in common between strangers as well as the object of revelation and demonstration. The importance of multi-sensory investigation was also shown throughout the experiments and in the enactment of the material-objects. The design of a material-object has been shown to influence that which can be communicated by it. If a material-object is very 'objecty' it may speak greatly of our cultural relationships to forms and functions at the expense of revealing its material properties, be these formally scientific or senso-aesthetic. The material-objects explored in this thesis have offered experientially orientated encounters with the science of their materials alongside investigations into their senso-aesthetics.

4 The role of the expert.

The multiplicity of roles adopted by the 'expert' have been discussed in this thesis and shown to be paramount within the context of the Materials Library and in materials encounter, especially when considering the revelation of technical knowledge and narrative links. The expert is the magician who reveals and conceals the tricks and talents of the material-object and directs, delights and dazzles the audience. They are able to bring theory and practice together in the physical demonstration of their craft and display their expertise as a materials practitioner, for the benefit of those seeking materials knowledge.

5 Contribution to knowledge.

The work of this thesis has contributed to the knowledge of a vast number of disciplines, both practical and academic. Since the establishment of the Materials Library, six new materials collections have opened around the world and specifically sought curatorial advice from the author (including the IOM3's MRC featured in chapter 2). Conference organisers in the fields of Art, Design, Anthropology, Materials Culture, Geography, Ethnography, Archaeology and Performance Studies have all invited the author to present her work (see Appendix A). The work has also been presented to materials science communities in the form of conference presentations, proceedings and posters (listed in Appendix A). A peer reviewed paper on the Taste of Materials has been submitted for publication to

The Journal of Food Preference and Quality. Public talks, performances, exhibitions and events (also listed in Appendix A) have also seen the work of this thesis disseminated in the pubic domain. As a resource, the Materials Library has been of use, interest and inspiration to hundreds of partitioners from a wide range of professions. In recognition of this, the Materials Library has recently been awarded a grant of £250,000 from the Leverhulme Trust (ref: F/07 040/AF) in order to bring together communities interested in materials for the sharing, exploration and advancement of material-based knowledge.

grant F/07 040/AF from the Leverhulme Trust

6 Future work.

As a result of the Leverhulme grant and the standing of the Materials Library project within King's College London (recognised as an entirety with a successful track record in public engagement), the Materials Library will be moving into the newly purchased East Wing of Somerset House in the autumn of 2011. The area allocated to the Materials Library is ten times bigger than its current home and will be tailored to the needs of the materials and activities it will host. Within this new setting, and with regard to future work in general, there is vast scope for the exploration of the isomorphic methodology in relation to the creation of new sets of material-objects. Such sets would explore the nexus of material-objects and enable a greater exploration of the notion of the material-object continuum. Sets that explore the axis of function/performance would be particularly interesting to explore in order to investigate and demonstrate the effect of materiality on the function of objects. Expanding the current sets of material-objects presented in this thesis is another avenue for future work; more cubes, tuning forks or a wooden bell, for example, would expand the nexus of material-objects present within the Library collection. Further experiments could be conducted with the material-objects. The spoons, for example, could be used to determine the effect materials may have in relation to the taste of specific foods. Future work could also be done in the field of ethnography in relation to the use and understanding of material evidence as an indication of human interactions with objects and a signifier of specific behaviours. To this end a forensic ethnography could be proposed to apply quantifiable scientific data to qualitative issues of interaction. And finally, it is clear that more work could be done to study and critique the rapidly expanding world of materials libraries, a topic that warrants interdisciplinary analysis.

Appendix A

Outputs in the Public Domain

Conference Contributions

2009

Investigating the Taste of Materials with Spoons, Conference Poster, published in proceedings, Measuring the Impossible, MINET & NPL, London, 2009.

Material Landscapes, opening and closing adresses as Invited Interlocutor, Living Landscapes, UWA, Aberystwyth, Wales, 2009.

2008

Investigating the Acoustic Properties of Materials with Tuning Forks, and *Building a Materials Library using an Isomorphic Methodology*, Conference Papers, published in proceedings, Materials Sensation, Pau, France 2008.

The Performativity of Matter, Invited Performance Lecture, Theatre Materials/Materials Theatre, Central School of Speech and Drama, London, 2008. Subsequently published in *Theatre Materials: What Is Theatre Made Of?*, published by the Centre for Excellence in Training for Theatre, ISBN: 978-0-9539501-5-7, 2009.

Materials for the Advancement of Conceptualisation, Conference Paper, Pedagogy and Practice, Institute of Germanic & Romance Studies, London 2008.

2007

A Sound Forecast, Invited Presentation, Prognosen über Bewegungen, University of Berlin, 2007.

Landscapes Within Liquids, Invited Presentation, Royal Geographical Society's annual conference, London, 2007.

The Materials Library, Invited Presentation, Material Beliefs, Goldsmiths College, London, 2007.

2006

The Materials Library, Invited Presentation, Materials of Invention, Building Centre, London, 2006.

Materials Library Presents, Invited Presentation, Science in the Making, Kings College London, 2006.

Public Talks and Performances

2009

The Taste of Materials, Talk, 100% Materials, 100% Design, London, 2009.

The Wonders of Stuff, Talk, Women in Science, Science Museum, London, 2009.

The Sound of Materials, Performance and Talk, STUK Arts Centre, Leaven, Belgium, 2009.

2008

Materials: A Demonstration, Performance and Talk, 176 Gallery, London, 2008.

The Materials Library, Talk, Kenetica, London, 2008.

Micro Macro and *Smelting Melting Casting*, Materials Experiment, Royal College of Art, 2008.

Materials Matters, Talk, 100% Materials, 100% Design, London, 2008.

The Performativity of Matter, Performance Lecture, ICA, London 2008.

The Materials Library, Talk, LCACE, London, 2008.

What Materials Get Up To, Talk, Nottingham Cinema Arts Centre, 2008.

What Can The Matter Be? II Talk, Starr Auditorium, Tate Modern, London, 2008.

2007

The Wonders of Stuff: The Materials Library, Talk, South Bank University, London, 2007.

The Wonders of Stuff: The Materials Library, Talk, University of The Arts, London, 2007.

The Sound of Matrials, Talk, 100% Materials, 100% Design, London, 2007.

The Materials Library, Talk, Librarians Workshop, London, 2007.

What Can the Matter Be? Talk, Starr Auditorium, Tate Modern, London, 2007.

The Materials Library, Talk, Department of Materials, Sheffield University, Sheffield, 2007.

The Sound of Materials, Performance andTalk, Tate Modern, London, 2007.

Events and Exhibitions

2009

Materials Library Take on Ceramics, The Victoria & Albert Museum, London, 2009.

Smelting Melting Casting, Secret Garden Party Festival, Cambridge, 2009.

2008

Hair, Wellcome Collection, London, 2008.

Smelting Melting Casting, Cheltenham Science Festival, 2008.

2007

Flesh, Wellcome Collection, London, 2007.

The Sound of Materials, Tate Modern, London, 2007.

What Can The Matter Be? A podcast for Tate Modern, London, 2008.

2006

The Essence of Fluorescence, The Hayward Gallery, London, 2006.

Materials Library on the Road, San Antonio, Texas, USA, 2006.

Crystacast Prototype Thermochromic Brick, The Building Centre, London, 2006.

Materials Library on the Road, Cheltenham Science Festival, 2006.

The Bicycle of the Future, The Big Draw, Somerset House, London, 2006.

Materials Library Presents... Tate Modern, Tate Modern, London, 2006.

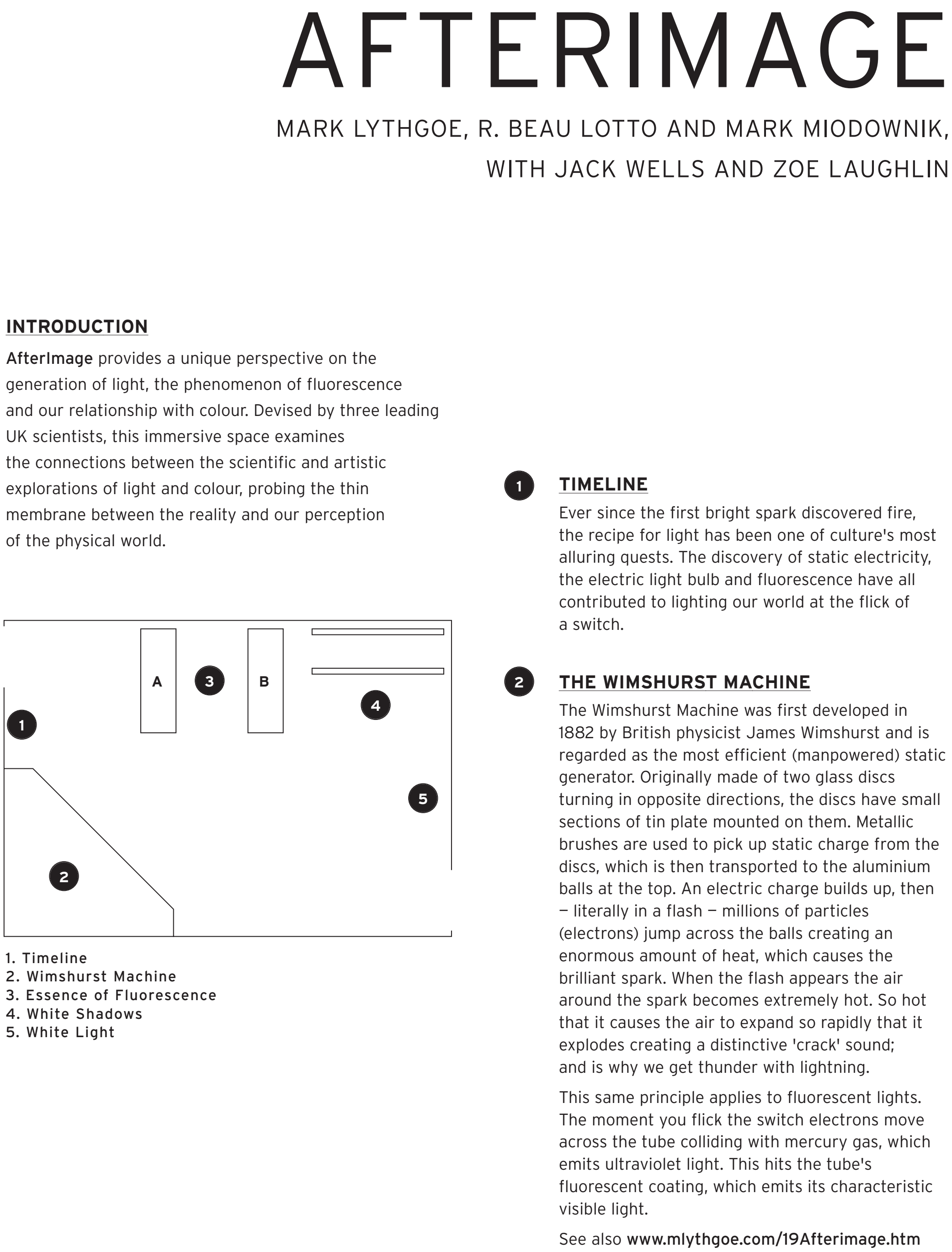
2005

Impermanence Materials, Impermanence, Tate Modern, London, 2005.

Material Matters, Materials Library, Kings College London, London, 2005.

Appendix B

The Essence of Fluorescence Handout



AFTERIMAGE

MARK LYTHGOE, R. BEAU LOTTO AND MARK MIODOWNIK,
WITH JACK WELLS AND ZOE LAUGHLIN

INTRODUCTION

AfterImage provides a unique perspective on the generation of light, the phenomenon of fluorescence and our relationship with colour. Devised by three leading UK scientists, this immersive space examines the connections between the scientific and artistic explorations of light and colour, probing the thin membrane between the reality and our perception of the physical world.

1. Timeline
2. Wimshurst Machine
3. Essence of Fluorescence
4. White Shadows
5. White Light

① TIMELINE

Ever since the first bright spark discovered fire, the recipe for light has been one of culture's most alluring quests. The discovery of static electricity, the electric light bulb and fluorescence have all contributed to lighting our world at the flick of a switch.

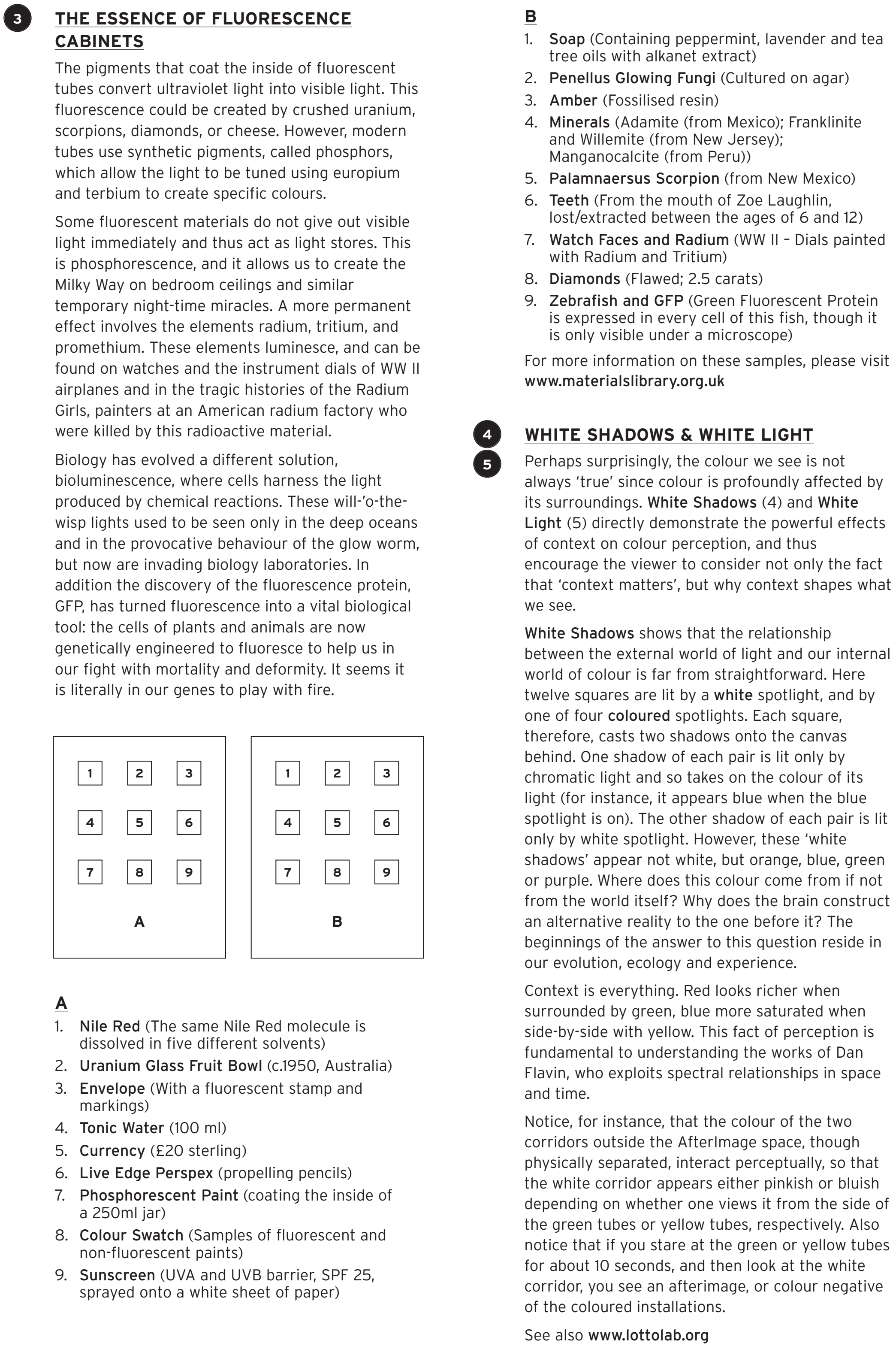
② THE WIMSHURST MACHINE

The Wimshurst Machine was first developed in 1882 by British physicist James Wimshurst and is regarded as the most efficient (manpowered) static generator. Originally made of two glass discs turning in opposite directions, the discs have small sections of tin plate mounted on them. Metallic brushes are used to pick up static charge from the discs, which is then transported to the aluminium balls at the top. An electric charge builds up, then – literally in a flash – millions of particles (electrons) jump across the balls creating an enormous amount of heat, which causes the brilliant spark. When the flash appears the air around the spark becomes extremely hot. So hot that it causes the air to expand so rapidly that it explodes creating a distinctive 'crack' sound; and is why we get thunder with lightning.

This same principle applies to fluorescent lights. The moment you flick the switch electrons move across the tube colliding with mercury gas, which emits ultraviolet light. This hits the tube's fluorescent coating, which emits its characteristic visible light.

See also **www.mlythgoe.com/19Afterimage.htm**

Figure B.1: *The Essence of Fluorescence* handout, page 2/1.



③ **THE ESSENCE OF FLUORESCENCE CABINETS**

The pigments that coat the inside of fluorescent tubes convert ultraviolet light into visible light. This fluorescence could be created by crushed uranium, scorpions, diamonds, or cheese. However, modern tubes use synthetic pigments, called phosphors, which allow the light to be tuned using europium and terbium to create specific colours.

Some fluorescent materials do not give out visible light immediately and thus act as light stores. This is phosphorescence, and it allows us to create the Milky Way on bedroom ceilings and similar temporary night-time miracles. A more permanent effect involves the elements radium, tritium, and promethium. These elements luminesce, and can be found on watches and the instrument dials of WW II airplanes and in the tragic histories of the Radium Girls, painters at an American radium factory who were killed by this radioactive material.

Biology has evolved a different solution, bioluminescence, where cells harness the light produced by chemical reactions. These will-'o-the-wisp lights used to be seen only in the deep oceans and in the provocative behaviour of the glow worm, but now are invading biology laboratories. In addition the discovery of the fluorescence protein, GFP, has turned fluorescence into a vital biological tool: the cells of plants and animals are now genetically engineered to fluoresce to help us in our fight with mortality and deformity. It seems it is literally in our genes to play with fire.

A

1. **Nile Red** (The same Nile Red molecule is dissolved in five different solvents)
2. **Uranium Glass Fruit Bowl** (c.1950, Australia)
3. **Envelope** (With a fluorescent stamp and markings)
4. **Tonic Water** (100 ml)
5. **Currency** (£20 sterling)
6. **Live Edge Perspex** (propelling pencils)
7. **Phosphorescent Paint** (coating the inside of a 250ml jar)
8. **Colour Swatch** (Samples of fluorescent and non-fluorescent paints)
9. **Sunscreen** (UVA and UVB barrier, SPF 25, sprayed onto a white sheet of paper)

B

1. **Soap** (Containing peppermint, lavender and tea tree oils with alkanet extract)
2. **Penellus Glowing Fungi** (Cultured on agar)
3. **Amber** (Fossilised resin)
4. **Minerals** (Adamite (from Mexico); Franklinite and Willemite (from New Jersey); Manganocalcite (from Peru))
5. **Palamnaersus Scorpion** (from New Mexico)
6. **Teeth** (From the mouth of Zoe Laughlin, lost/extracted between the ages of 6 and 12)
7. **Watch Faces and Radium** (WW II – Dials painted with Radium and Tritium)
8. **Diamonds** (Flawed; 2.5 carats)
9. **Zebrafish and GFP** (Green Fluorescent Protein is expressed in every cell of this fish, though it is only visible under a microscope)

For more information on these samples, please visit **www.materialslibrary.org.uk**

④ ⑤ **WHITE SHADOWS & WHITE LIGHT**

Perhaps surprisingly, the colour we see is not always 'true' since colour is profoundly affected by its surroundings. **White Shadows** (4) and **White Light** (5) directly demonstrate the powerful effects of context on colour perception, and thus encourage the viewer to consider not only the fact that 'context matters', but why context shapes what we see.

White Shadows shows that the relationship between the external world of light and our internal world of colour is far from straightforward. Here twelve squares are lit by a **white** spotlight, and by one of four **coloured** spotlights. Each square, therefore, casts two shadows onto the canvas behind. One shadow of each pair is lit only by chromatic light and so takes on the colour of its light (for instance, it appears blue when the blue spotlight is on). The other shadow of each pair is lit only by white spotlight. However, these 'white shadows' appear not white, but orange, blue, green or purple. Where does this colour come from if not from the world itself? Why does the brain construct an alternative reality to the one before it? The beginnings of the answer to this question reside in our evolution, ecology and experience.

Context is everything. Red looks richer when surrounded by green, blue more saturated when side-by-side with yellow. This fact of perception is fundamental to understanding the works of Dan Flavin, who exploits spectral relationships in space and time.

Notice, for instance, that the colour of the two corridors outside the AfterImage space, though physically separated, interact perceptually, so that the white corridor appears either pinkish or bluish depending on whether one views it from the side of the green tubes or yellow tubes, respectively. Also notice that if you stare at the green or yellow tubes for about 10 seconds, and then look at the white corridor, you see an afterimage, or colour negative of the coloured installations.

See also **www.lottolab.org**

Figure B.2: *The Essence of Fluorescence* handout, page 2/2.

Appendix C

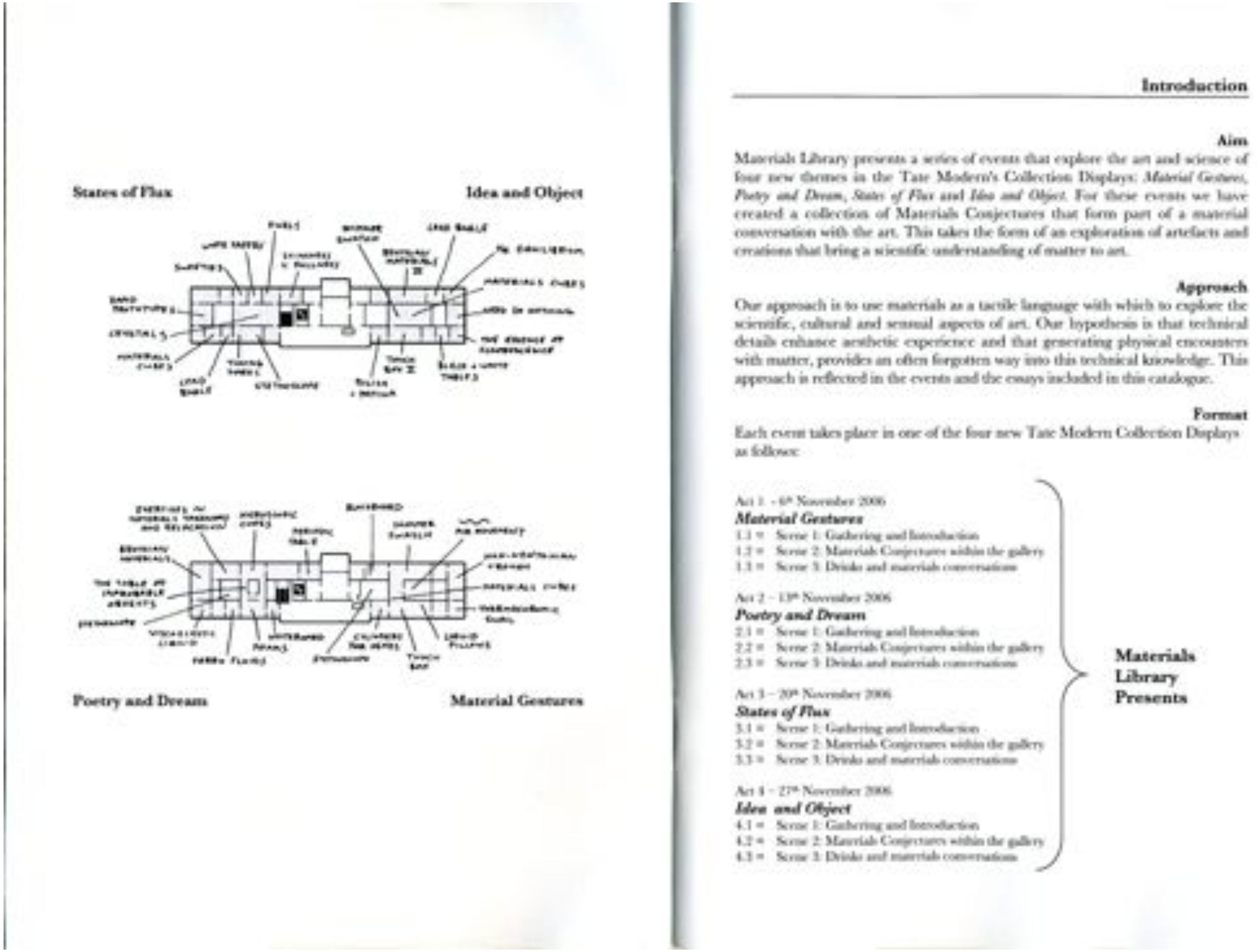
Materials Library Presents Booklet

Figure C.1: Front Cover (page 1)

Materials Library Presents
Tate Modern

Conreen, Laughlin, Miodownik
November 2006

Figure C.2: Pages 2 – 3



Introduction

Aim

Materials Library presents a series of events that explore the art and science of four new themes in the Tate Modern's Collection Displays: *Material Gestures*, *Poetry and Dream*, *States of Flux* and *Idea and Object*. For these events we have created a collection of Materials Conjectures that form part of a material conversation with the art. This takes the form of an exploration of artefacts and creations that bring a scientific understanding of matter to art.

Approach

Our approach is to use materials as a tactile language with which to explore the scientific, cultural and sensual aspects of art. Our hypothesis is that technical details enhance aesthetic experience and that generating physical encounters with matter, provides an often forgotten way into this technical knowledge. This approach is reflected in the events and the essays included in this catalogue.

Format

Each event takes place in one of the four new Tate Modern Collection Displays as follows:

Act 1 - 6th November 2006
Material Gestures
1.1 = Scene 1: Gathering and Introduction
1.2 = Scene 2: Materials Conjectures within the gallery
1.3 = Scene 3: Drinks and materials conversations

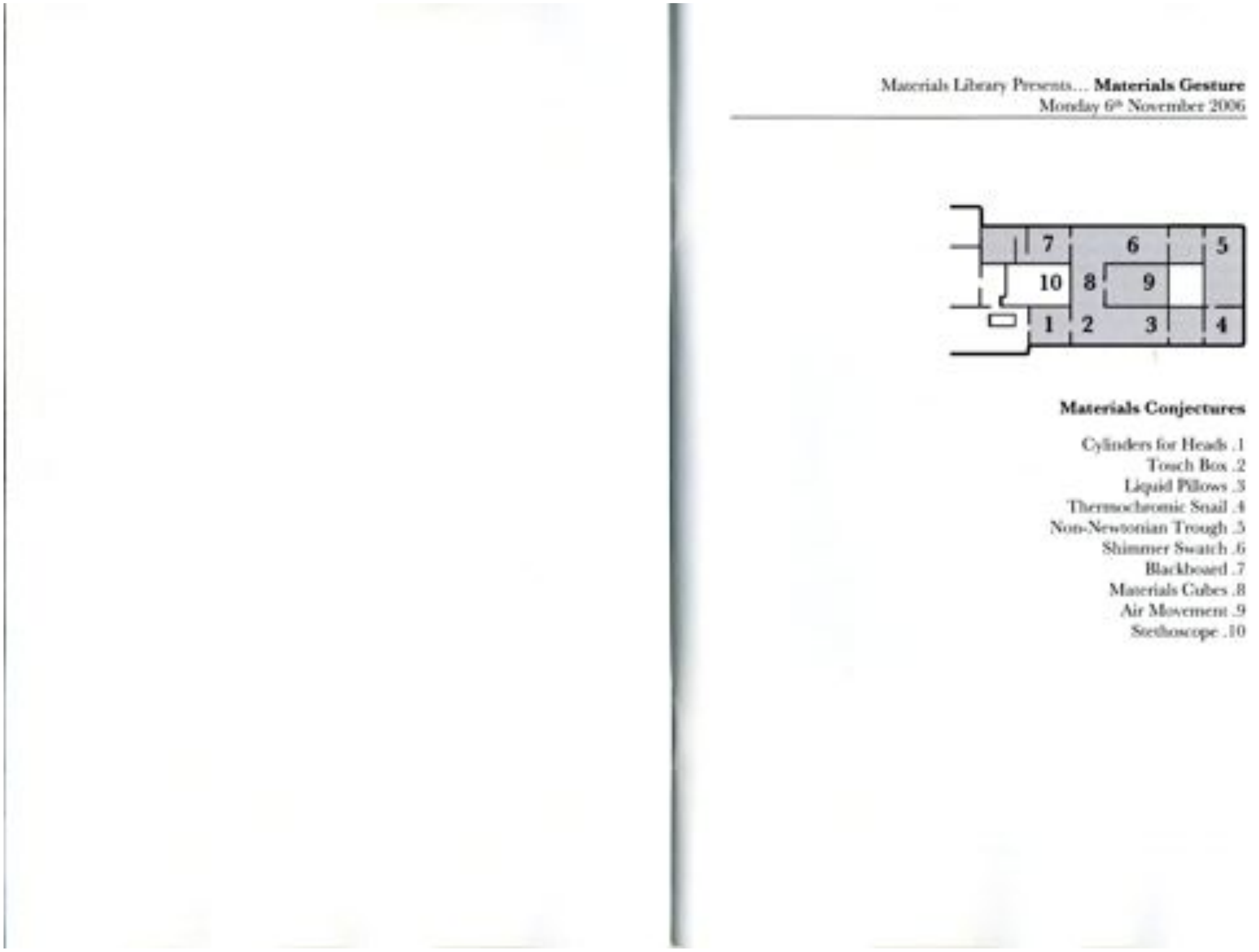
Act 2 - 13th November 2006
Poetry and Dream
2.1 = Scene 1: Gathering and Introduction
2.2 = Scene 2: Materials Conjectures within the gallery
2.3 = Scene 3: Drinks and materials conversations

Act 3 – 20th November 2006
States of Flux
3.1 = Scene 1: Gathering and Introduction
3.2 = Scene 2: Materials Conjectures within the gallery
3.3 = Scene 3: Drinks and materials conversations

Act 4 - 27th November 2006
Idea and Object
4.1 = Scene 1: Gathering and Introduction
4.2 = Scene 2: Materials Conjectures within the gallery
4.3 = Scene 3: Drinks and materials conversations

Materials
Library
Presents

Figure C.3: Pages 4 – 5



Materials Library Presents... **Materials Gesture**
Monday 6th November 2006

Materials Conjectures

Cylinders for Heads .1
Touch Box .2
Liquid Pillows .3
Thermochromic Snail .4
Non-Newtonian Trough .5
Shimmer Swatch .6
Blackboard .7
Materials Cubes .8
Air Movement .9
Stethoscope .10

Figure C.4: Pages 6 – 7

A Touchy Subject

Touch is the first sense to develop in the womb. By ten weeks a foetus responds to a touch on its cheek and starts building a tactile model of its world. Childhood toys are full of shapes and textures, which stimulate the haptic regions of the brain. Kissing, sucking, eating, chewing, breaking and throwing, are all methods of haptic investigation that enable us to create an understanding of the world around us. Actions like crawling and walking, all require our sense of touch to develop to a high level of sophistication. However, after childhood, unless afflicted by blindness, our haptic sense becomes dormant and the visual becomes the primary method of interrogating the world. This is obviously not just in the hierarchy of our cultural and intellectual institutions but also of day-to-day life. Supermarkets have discovered that it is the look, rather than the feel or taste of produce that determines their popularity. Design shops are full of chairs that look cool and stylish but are insanely uncomfortable. Fashionable clothing is designed to look good but very rarely to feel good. Ditto shoes. The epitome of this trend is lingerie, where a lacy thong or tight corsets create a physical discomfort that is endured for the visual pleasures they stimulate.

In adult life, our direct sense of the world is abstracted to, and mediated by, buttons and switches. Buttons on a keyboard, buttons on a phone, buttons in a car, buttons in the kitchen and buttons on remote controls. Even the buttons themselves are highly uniform, either being easy-to-clean minimalist affairs or spongy keyboard trampolines. Rarely does one come across the fluffy button, the sharp button or the button that requires at least two people to push it. We understand that to touch a button is to activate something but it is often forgotten that it is not only buttons that do this.

The button-orientated digital community are coming to grips with our need, desire and ability to sense our environments through touch. With this in mind they are developing virtual reality (VR) haptics. Touch is a notoriously difficult sense to simulate because it involves a complex mix of many different types of sensation: roughness, elasticity, thermal conductivity, electrical properties and chemical properties to name just a few. SensAble Technology's PHANToM, which allows a single point of force feedback to be simulated, is a basic first step towards VR touch: it has the form of a pen, but with an inverse functionality, it takes information and turns it into a force. The development of this VR technology and other 'glove' based approaches is vital to those developing virtual surgery as a technique to allow specialists to perform remote surgical operations all over the world. In this case, reliable mechanical feedback is a critical part of the ability to remotely manipulate objects such as scalpels and produce faithful haptic experiences. Museums are also interested in using this technology in order to allow the virtual handling of rare and delicate objects.

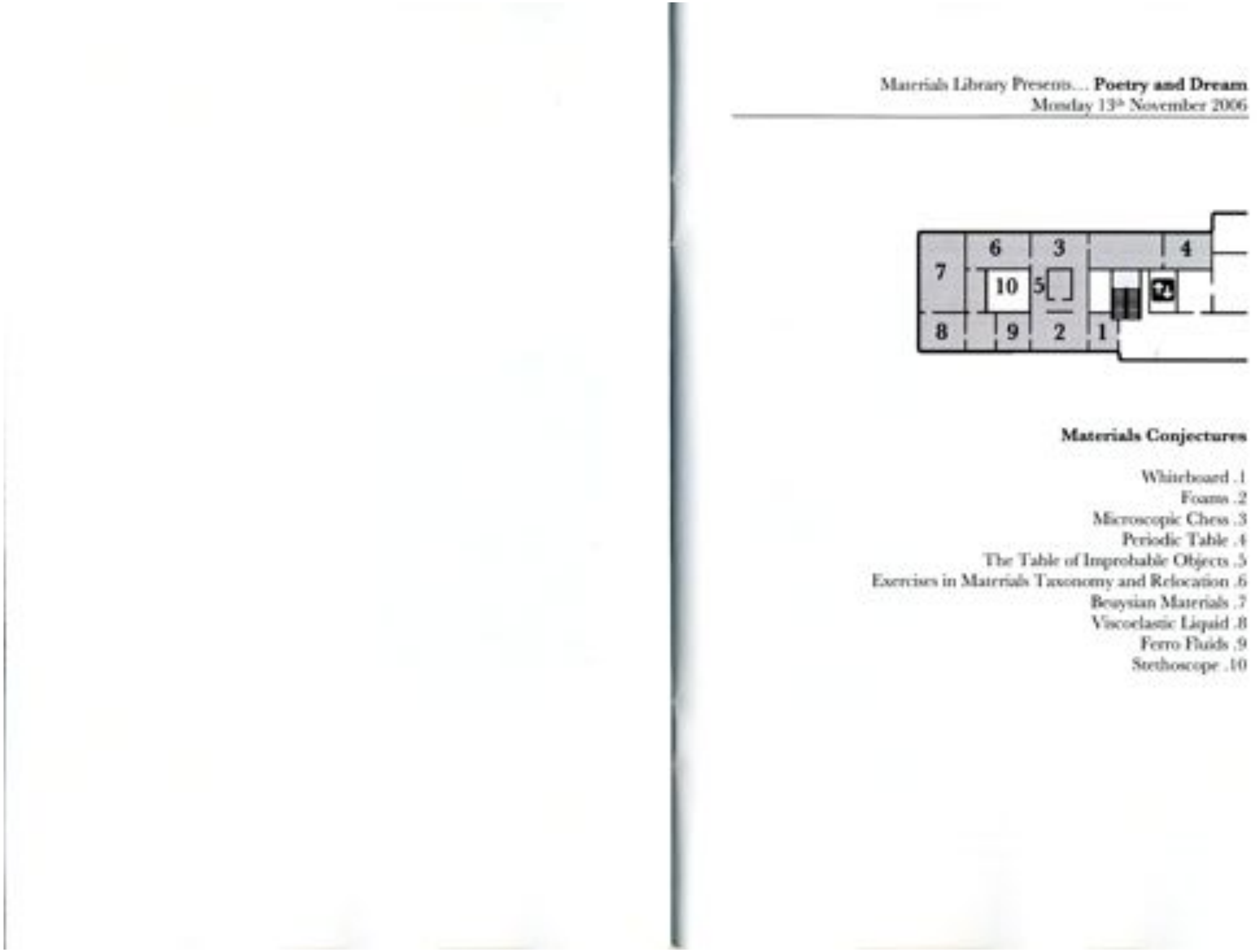
But of course, if VR touch technology follows the pattern of the internet, its expansion will almost certainly not be driven by these worthy aims but by the pornography industry's desire to offer the virtual touching of a different kind.

Both the haptic design of new materials and the development of VR touch require both a fundamental understanding of the science of materials as well as an understanding of the human sense of touch. Thus the advantages of multi-disciplinary teams are being recognised by industry. The first international workshop on Materials and Sensations was held in 2004 in Pau, France, and featured physicists, psychologists, materials scientists, designers and representatives from the fashion and cosmetics industries (www.2pam.fr). In 2005 the Victoria and Albert museum in London put on *Touch Me: design and sensation*, an exhibition that explored the pleasures, sensations and future of touch.

Lectures given without accompanying PowerPoint slides are in the minority and many people reach for a piece of paper to explain their point, but the communal engagement with objects and the tactile encountering of materials is rarely used as a learning aide. It seems odd that one can attend a lecture on the properties and uses of aluminium, for example, and not get a chance to manually manipulate a specimen. Equally one can read descriptions of the density and resultant heaviness of tungsten but it is not until one attempts to pick up a block of it that one begins to *know* the nature of the material. The idea of presenting data as a feeling, perhaps in the form of an object, is nonexistent in the sciences. Yet for many complex data sets this may be a far superior way to promote understanding, especially of forces and complex geometries. Architects and sculptors have been doing this for years, expressing information through form, but it is a pity that the 'please do not touch' culture of modern society prohibits us from accessing this information.

Picture Caption: Finger dipped in liquid latex during Materials Library's *Impermanent Materials* demonstration session at Tate Modern, November 2005. Photograph courtesy of Iona Ramsey.

Figure C.5: Pages 8 – 9

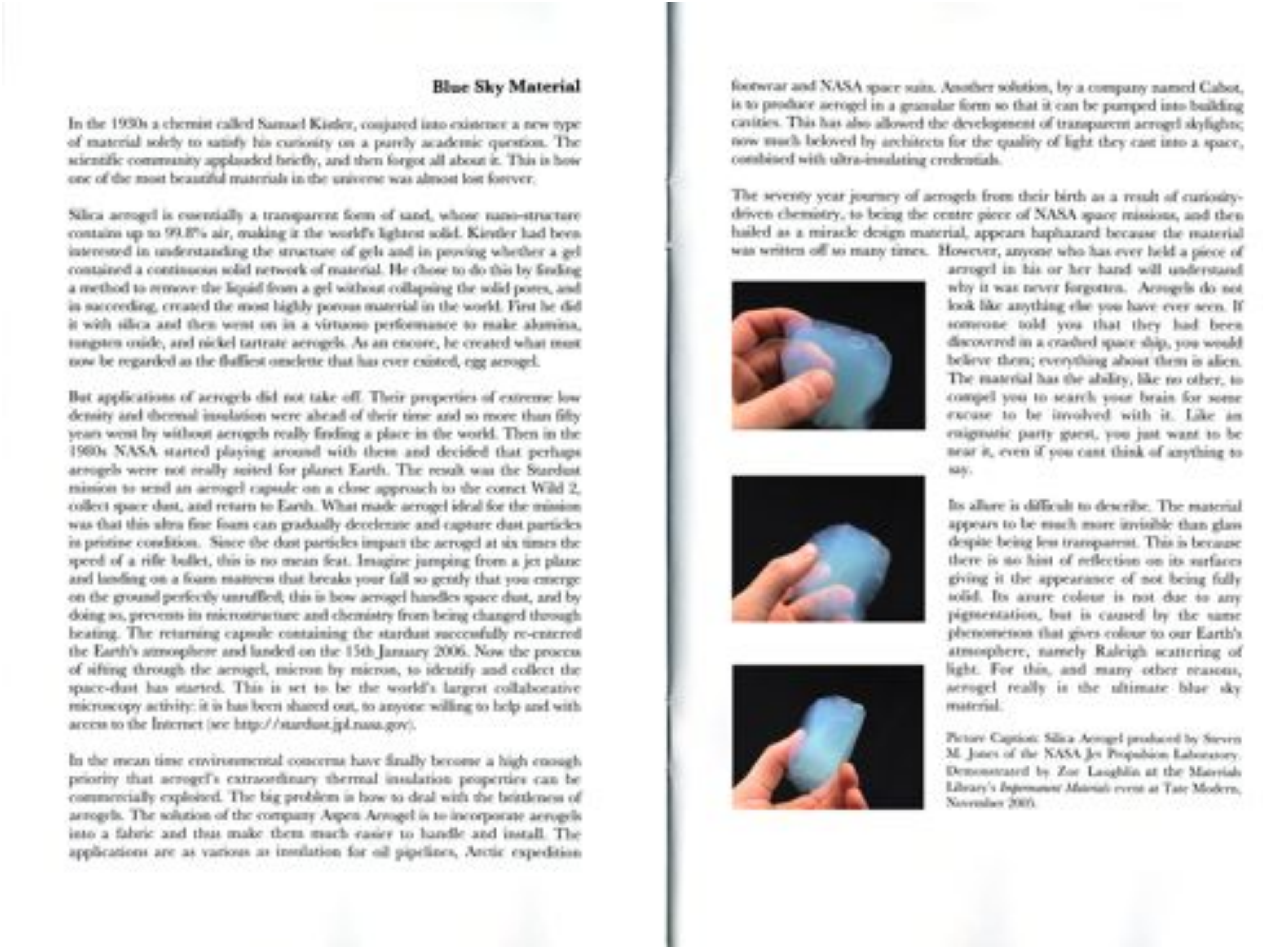


Materials Library Presents… **Poetry and Dream**
Monday 13th November 2006

Materials Conjectures

Whiteboard .1
Foams .2
Microscopic Chess .3
Periodic Table .4
The Table of Improbable Objects .5
Exercises in Materials Taxonomy and Relocation .6
Beuysian Materials .7
Viscoelastic Liquid .8
Ferro Fluids .9
Stethoscope .10

Figure C.6: Pages 10 – 11



Blue Sky Material

In the 1930s a chemist called Samuel Kistler, conjured into existence a new type of material solely to satisfy his curiosity on a purely academic question. The scientific community applauded briefly, and then forgot all about it. This is how one of the most beautiful materials in the universe was almost lost forever.

Silica aerogel is essentially a transparent form of sand, whose nano-structure contains up to 99.8% air, making it the world's lightest solid. Kistler had been interested in understanding the structure of gels and in proving whether a gel contained a continuous solid network of material. He chose to do this by finding a method to remove the liquid from a gel without collapsing the solid pores, and in succeeding, created the most highly porous material in the world. First he did it with silica and then went on in a virtuoso performance to make alumina, tungsten oxide, and nickel tartrate aerogels. As an encore, he created what must now be regarded as the fluffiest omelette that has ever existed, egg aerogel.

But applications of aerogels did not take off. Their properties of extreme low density and thermal insulation were ahead of their time and so more than fifty years went by without aerogels really finding a place in the world. Then in the 1980s NASA started playing around with them and decided that perhaps aerogels were not really suited for planet Earth. The result was the Stardust mission to send an aerogel capsule on a close approach to the comet Wild 2, collect space dust, and return to Earth. What made aerogel ideal for the mission was that this ultra fine foam can gradually decelerate and capture dust particles in pristine condition. Since the dust particles impact the aerogel at six times the speed of a rifle bullet, this is no mean feat. Imagine jumping from a jet plane and landing on a foam mattress that breaks your fall so gently that you emerge on the ground perfectly unruffled; this is how aerogel handles space dust, and by doing so, prevents its microstructure and chemistry from being changed through heating. The returning capsule containing the stardust successfully re-entered the Earth's atmosphere and landed on the 15th January 2006. Now the process of sifting through the aerogel, micron by micron, to identify and collect the space-dust has started. This is set to be the world's largest collaborative microscopy activity: it is has been shared out, to anyone willing to help and with access to the Internet (see http://stardust.jpl.nasa.gov).

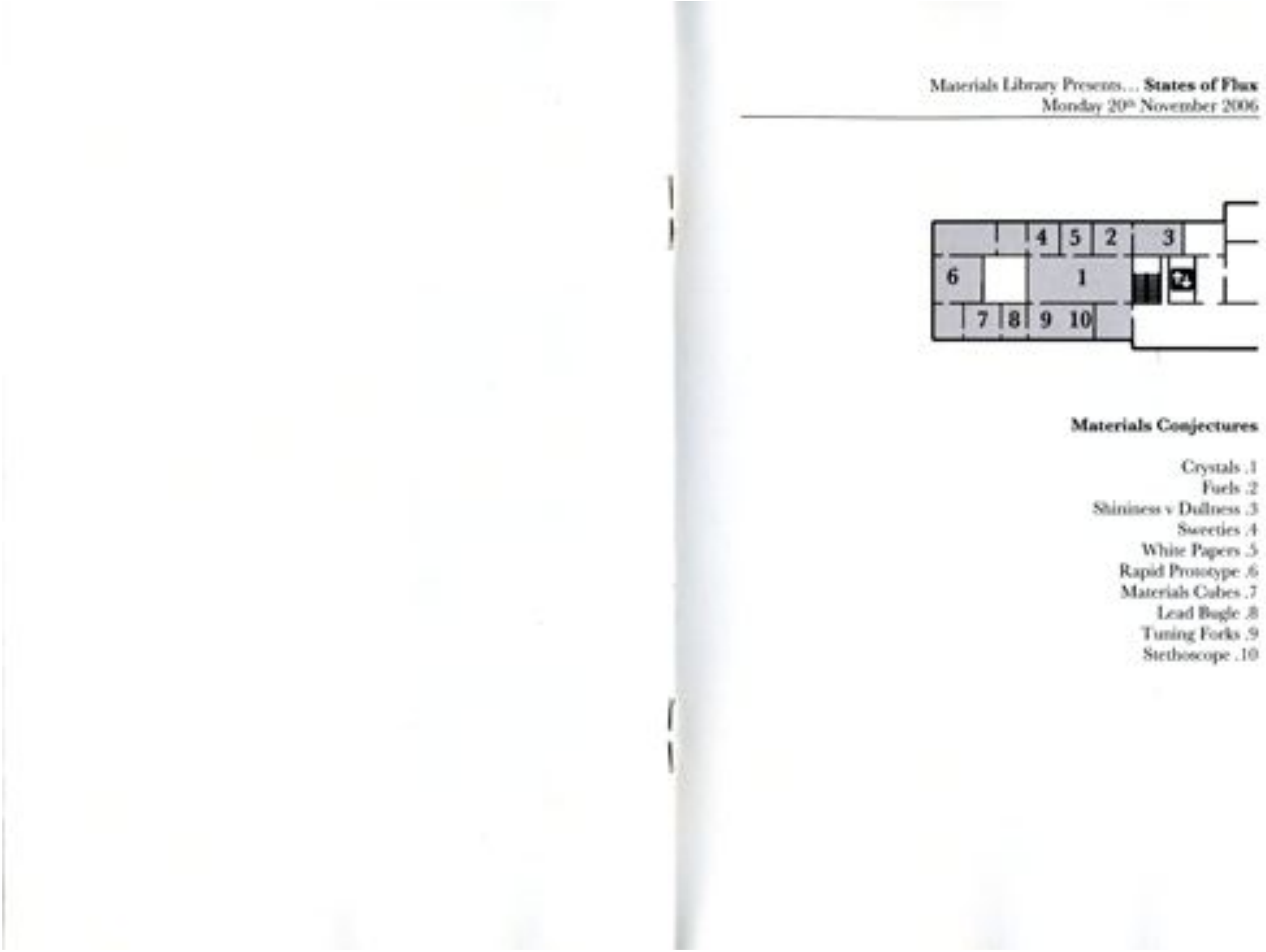
In the mean time environmental concerns have finally become a high enough priority that aerogel's extraordinary thermal insulation properties can be commercially exploited. The big problem is how to deal with the brittleness of aerogels. The solution of the company Aspen Aerogel is to incorporate aerogels into a fabric and thus make them much easier to handle and install. The applications are as various as insulation for oil pipelines, Arctic expedition footwear and NASA space suits. Another solution, by a company named Cabot, is to produce aerogel in a granular form so that it can be pumped into building cavities. This has also allowed the development of transparent aerogel skylights; now much beloved by architects for the quality of light they cast into a space, combined with ultra-insulating credentials.

The seventy year journey of aerogels from their birth as a result of curiosity-driven chemistry, to being the centre piece of NASA space missions, and then hailed as a miracle design material, appears haphazard because the material was written off so many times. However, anyone who has ever held a piece of aerogel in his or her hand will understand why it was never forgotten. Aerogels do not look like anything else you have ever seen. If someone told you that they had been discovered in a crashed space ship, you would believe them; everything about them is alien. The material has the ability, like no other, to compel you to search your brain for some excuse to be involved with it. Like an enigmatic party guest, you just want to be near it, even if you cant think of anything to say.

Its allure is difficult to describe. The material appears to be much more invisible than glass despite being less transparent. This is because there is no hint of reflection on its surfaces giving it the appearance of not being fully solid. Its azure colour is not due to any pigmentation, but is caused by the same phenomenon that gives colour to our Earth's atmosphere, namely Raleigh scattering of light. For this, and many other reasons, aerogel really is the ultimate blue sky material.

Picture Caption: Silica Aerogel produced by Steven M. Jones of the NASA Jet Propulsion Laboratory. Demonstrated by Zoe Laughlin at the Materials Library's *Impermanent Materials* event at Tate Modern, November 2005.

Figure C.7: Pages 12 – 13



Materials Library Presents… **States of Flux**
Monday 20th November 2006

Materials Conjectures

Crystals .1
Fuels .2
Shininess v Dullness .3
Sweeties .4
White Papers .5
Rapid Prototype .6
Materials Cubes .7
Lead Bugle .8
Tuning Forks .9
Stethoscope .10

Figure C.8: Pages 14 – 15

The Sound of Materials

We live in a visually orientated culture in which sight is foregrounded as the primary sense. It is no surprise that when talking about the world around us we allude to its visual qualities: a dazzling vista, an eye-catching jumper or a mesmerizing sunset. We describe people similarly, with reference to radiant beauties, luminescent complexions and eye-popping hunks: reinforcing the primacy of the visual. However, our sensual relationships with people are not based solely on looks; we care how they smell, how they feel, how they warm us, and how they sound. The same is true of our relationship with our environment in general.

We know the sounds of individual doors in our houses and can distinguish between someone leaving or entering from the delicate variations of keys rattling and hinges squeaking. You can identify any member of the family coming up the stairs from the subtle differences in rhythms and the pitch of the creaks produced. These acoustic qualities of a home are important but often overlooked. Carpeting over the tiles in the hall for example makes for a cozier surface under foot but at the same time the house loses its ability to announce a visitors choice of footwear: the squeak of rubber tennis soles, the tip-tap of stilettos and the solid thump of work boots are banished from the acoustic landscape of the home. Carpet acts on a home as a kind of auditory gag that mutes the sonic signatures of its inhabitants.

Whilst some sounds make us feel comfortable, relaxed and 'at home', others can unsettle and disturb us. An absence of sound can indeed be one of the most disquieting of acoustic effects. Each time the lock of a hotel room is replaced with silent swipe card access, we lose the reassuring sound of metal clanking into place in announcement of security. The token electronic beep that is sometimes inserted as a sonic cue to signal a successful swipe, evokes a wholly different set of audio connotations; those of the supermarket checkout or high street cash machine. Automotive engineers understand the importance of sound to signal security, reliability, safety and quality. It would be possible to totally insulate the inside of a car from engine noise but there is a degree to which the hum of the engine is a comfort to those within, as well as an aide to the driver when selecting a gear change. Good architects also know the value of acoustics and sonic signatures, putting as much attention into how a building will sound as to how it will look. Specific spaces require specific understandings of how sound is deflected and absorbed, allowing concert halls to reverberate the sinews of the audience (be they sat in the back or the front row) or people to have intimate conversations at a comfortable volume whilst having dinner in a crowded restaurant.

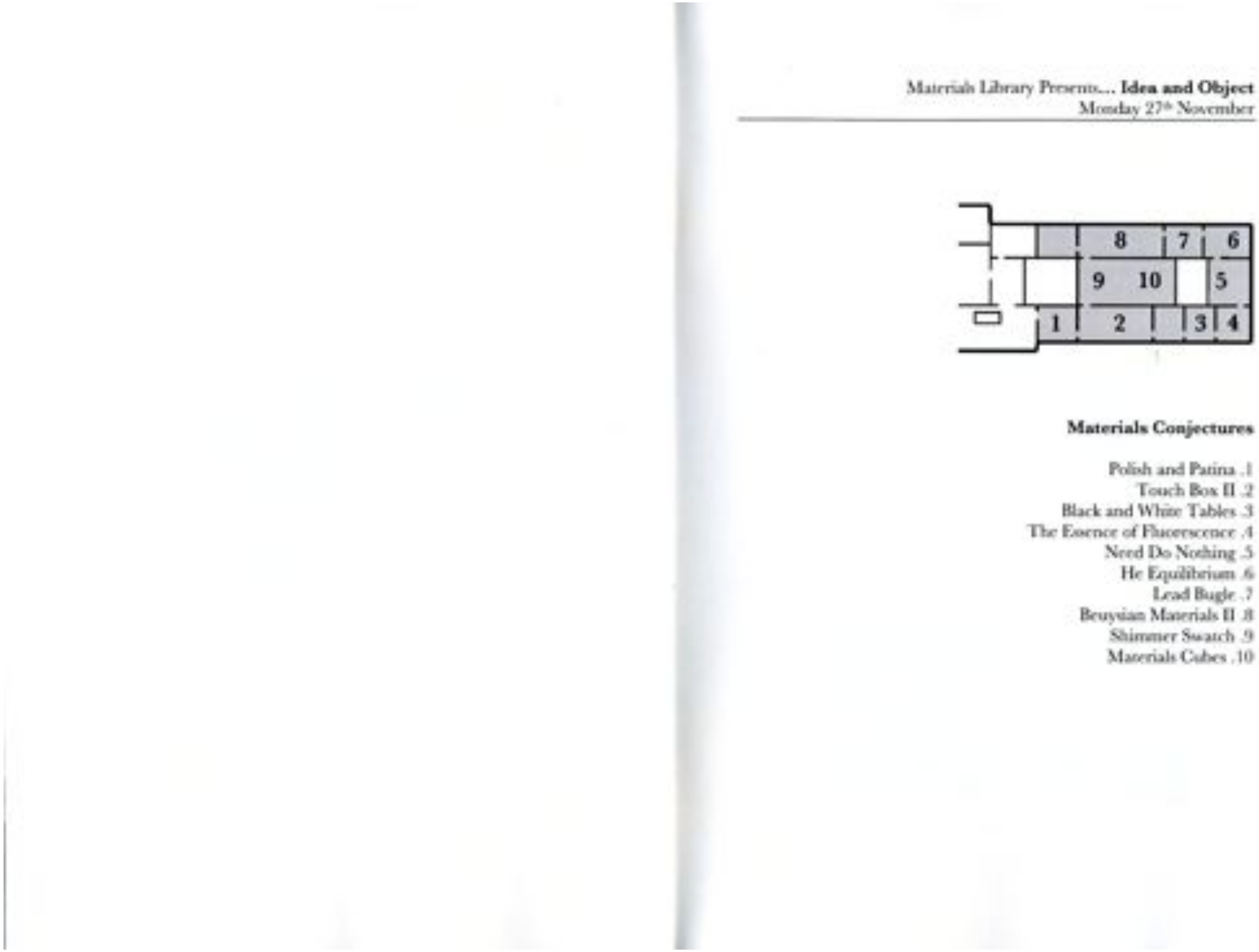
Sounds and their cultural resonances are built upon material relationships that produce specific acoustic effects. Imagine the sound of a prisoner running a polystyrene cup along the iron bars of the cell, as apposed to the archetypal enameled steel cup. We can all call to mind the sound of a stick running along railings but can we imagine how this sound would change if the railings were glass and the stick carbon fiber?

The materials science of acoustic properties has a long and interesting history starting from the early design of musical instruments. Brass trumpets range from very hard nickel-silver through to softer red and yellow brass and onto to an extremely soft am-bronze alloy. The pitch of instruments is linked to the material's modulus and density, whereas the 'brightness' of an instrument is linked to its loss coefficient, allowing higher overtones in the musical spectrum. Softer alloys tend to sound warmer and duller – lead being an extreme case.

Picture Caption: Lead Bugle created for Materials Library by Rex Garrod

Designing the acoustic properties of materials for instruments is thus a strange combination of art and science: it must take into account musicians cultural sensibilities and musical tastes, as well as the fundamental materials science of manipulating density, hardness and modulus while producing an alloy that can be formed or cast into the instrument's shape. The sophistication of church bell design is a good example of this, with artists, musicians and metallurgists all involved in designing powerful and unique sounds for civic buildings. The sound of Big Ben in the Houses Parliament in London is a good example of a bronze auditory signature of democracy; it is measured, grave and earnest. Sets of bells with unique peals have been culturally important throughout history, not only signaling time, but ringing out declarations of love on wedding days, tolling at death and warning of danger in times of war.

Figure C.9: Pages 16 – 17

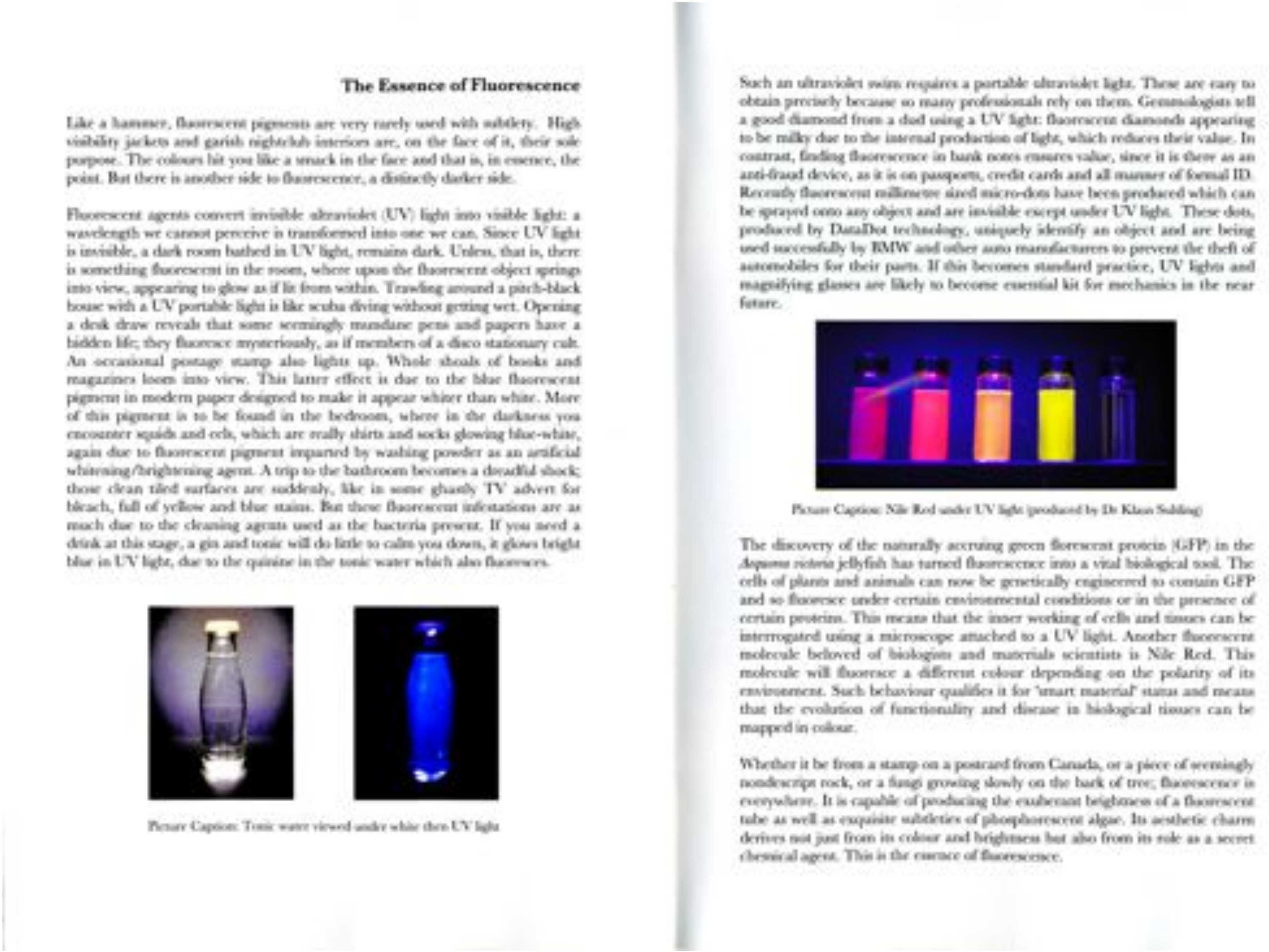


Materials Library Presents... **Idea and Object**
Monday 27th November

Materials Conjectures

Polish and Patina .1
Touch Box II .2
Black and White Tables .3
The Essence of Fluorescence .4
Need Do Nothing .5
He Equilibrium .6
Lead Bugle .7
Beuysian Materials II .8
Shimmer Swatch .9
Materials Cubes .10

Figure C.10: Pages 18 – 19



The Essence of Fluorescence

Like a hammer, fluorescent pigments are very rarely used with subtlety. High visibility jackets and garish nightclub interiors are, on the face of it, their sole purpose. The colours hit you like a smack in the face and that is, in essence, the point. But there is another side to fluorescence, a distinctly darker side.

Fluorescent agents convert invisible ultraviolet (UV) light into visible light: a wavelength we cannot perceive is transformed into one we can. Since UV light is invisible, a dark room bathed in UV light, remains dark. Unless, that is, there is something fluorescent in the room, where upon the fluorescent object springs into view, appearing to glow as if lit from within. Trawling around a pitch-black house with a UV portable light is like scuba diving without getting wet. Opening a desk draw reveals that some seemingly mundane pens and papers have a hidden life; they fluoresce mysteriously, as if members of a disco stationary cult. An occasional postage stamp also lights up. Whole shoals of books and magazines loom into view. This latter effect is due to the blue fluorescent pigment in modern paper designed to make it appear whiter than white. More of this pigment is to be found in the bedroom, where in the darkness you encounter squids and eels, which are really shirts and socks glowing blue-white, again due to fluorescent pigment imparted by washing powder as an artificial whitening/brightening agent. A trip to the bathroom becomes a dreadful shock; those clean tiled surfaces are suddenly, like in some ghastly TV advert for bleach, full of yellow and blue stains. But these fluorescent infestations are as much due to the cleaning agents used as the bacteria present. If you need a drink at this stage, a gin and tonic will do little to calm you down, it glows bright blue in UV light, due to the quinine in the tonic water which also fluoresces.

Picture Caption: Tonic water viewed under white then UV light

Such an ultraviolet swim requires a portable ultraviolet light. These are easy to obtain precisely because so many professionals rely on them. Gemmologists tell a good diamond from a dud using a UV light: fluorescent diamonds appearing to be milky due to the internal production of light, which reduces their value. In contrast, finding fluorescence in bank notes ensures value, since it is there as an anti-fraud device, as it is on passports, credit cards and all manner of formal ID. Recently fluorescent millimetre sized micro-dots have been produced which can be sprayed onto any object and are invisible except under UV light. These dots, produced by DataDot technology, uniquely identify an object and are being used successfully by BMW and other auto manufacturers to prevent the theft of automobiles for their parts. If this becomes standard practice, UV lights and magnifying glasses are likely to become essential kit for mechanics in the near future.

Picture Caption: Nile Red under UV light (produced by Dr Klaus Suhling)

The discovery of the naturally accruing green florescent protein (GFP) in the *Aequorea victoria* jellyfish has turned fluorescence into a vital biological tool. The cells of plants and animals can now be genetically engineered to contain GFP and so fluoresce under certain environmental conditions or in the presence of certain proteins. This means that the inner working of cells and tissues can be interrogated using a microscope attached to a UV light. Another fluorescent molecule beloved of biologists and materials scientists is Nile Red. This molecule will fluoresce a different colour depending on the polarity of its environment. Such behaviour qualifies it for 'smart material' status and means that the evolution of functionality and disease in biological tissues can be mapped in colour.

Whether it be from a stamp on a postcard from Canada, or a piece of seemingly nondescript rock, or a fungi growing slowly on the bark of tree; fluorescence is everywhere. It is capable of producing the exuberant brightness of a fluorescent tube as well as exquisite subtleties of phosphorescent algae. Its aesthetic charm derives not just from its colour and brightness but also from its role as a secret chemical agent. This is the essence of fluorescence.

Figure C.11: Pages 20 – 21

Picture Caption: Materials Library Group performing Wax Lyrical, a piece composed for wax instruments, at The Cheltenham Science Festival, June 2006.

The Materials Library Approach

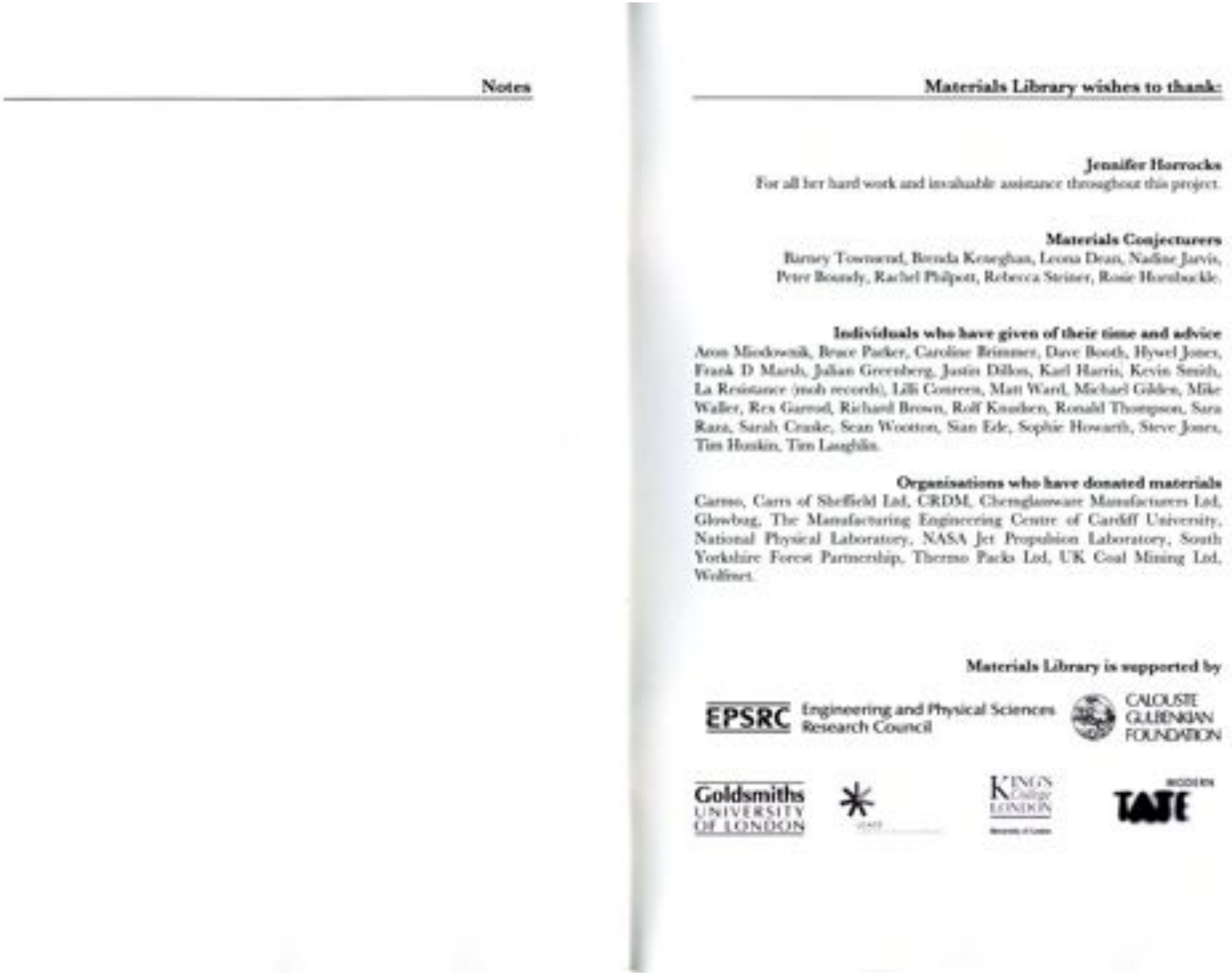
There are materials libraries in New York, Amsterdam, Berlin, Paris, and London. Apart from a commonality of purpose, these materials libraries share very little else. Unlike libraries of books, which have had hundreds of years in which to refine and agree on standards, formats and taxonomy, the materials library as a formal concept is barely ten years old. Some libraries exist primarily as a searchable database, with a much smaller physical archive of samples. Others exist as a specialised reference library on a particular topic for a particular type of practitioner.

Our approach is different. We believe that materials are a language that we all use to communicate not only with each other, but also with the past and the future. The arts are expert in this language of the senses and so it is clear that they need materials libraries as creative tools, much as a novelist needs a traditional library. But here the similarity ends. It makes no sense to talk about the science of words, but the science of a material is vital knowledge that underpins the art, craft and mastery of all materials. So to our mind, a materials library without an interface with the science is like a library without an index, fun but frustrating.

A chunk of Aerogel from the Jet Propulsion Laboratory of NASA that, at 99.8% air, is the worlds lightest solid; a tile of aluminium nitride that conducts the heat from one's hand efficiently enough to cut ice as if it were butter; a Lead Bugle: in the Materials Library these materials are gathered together not only for scientific interest, but for their ability to fire the imagination and advance conceptualisation. Our hypothesis is that not only are technical details essential for makers, they also enhance aesthetic experience and that in generating physical encounters with matter, one provides an often forgotten way into this technical knowledge.

materials*Library*

Figure C.12: Pages 22 – 23



Notes

Materials Library wishes to thank:

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Materials Conjecturers
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CALOUSTE GULBENKIAN FOUNDATION

Goldsmiths UNIVERSITY OF LONDON

KING'S College LONDON

MODERN TATE

Figure C.13: Pages 24 – 25

materials*Library*
presents...

www.materialslibrary.org.uk

Figure C.14: Back Cover (page 26)

Appendix D

Flesh Handout

Figure D.1: *Flesh* handout; front.

WELCOME

How often do we consider flesh as a material, with properties and behaviours that make it truly wondrous stuff? This event is a celebration of flesh in all its glorious forms, from bacon and biceps to figs and fat. No more 'please do not touch'; Materials Library invite you to join them and their expert guests in an evening of hands-on encounters with the materiality of flesh.

TIME TABLE

ENTRANCE (ground floor)	Bodybuilder performance 18.45 Rock/paper/scissors cutting test 18.30–22.00
AUDITORIUM (lower ground 1)	Introduction from Materials Library & guests 19.00–19.30
FORUM (first floor)	Life drawing class 19.45–20.30 and 20.45–21.30
MEDICINE NOW (first floor)	Hands-on conjectures 19.45–22.00
MEDICINE MAN (first floor)	Touch-box conjectures 19.45–22.00

This is one of a series of thematic events inspired by the collections. For further information and to sign up for email updates, please visit **www.wellcomecollection.org**.

Figure D.2: *Flesh* handout; after opening first fold revealing detachable plaster.

WELCOME

How often do we consider flesh as a material, with properties and behaviours that make it truly wondrous stuff? This event is a celebration of flesh in all its glorious forms, from bacon and biceps to figs and fat. No more 'please do not touch'; Materials Library invite you to join them and their expert guests in an evening of hands-on encounters with the materiality of flesh.

TIME TABLE

18.30 19.30 20.30 21.30

ENTRANCE (ground floor)
Bodybuilder performance 18.45
Rock/paper/scissors cutting test 18.30–22.00

AUDITORIUM (lower ground 1)
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MEDICINE MAN (first floor)
Touch-box conjectures 19.45–22.00

This is one of a series of thematic events inspired by the collections. For further information and to sign up for email updates, please visit **www.wellcomecollection.org**.

ENTRANCE

18.30–22.00
Can you give a peach a paper cut? What wins: rock, paper or scissors? Try your hand at cutting fruit flesh with a flint, a strip of paper and a pair of scissors.

18.45
British champion bodybuilder Troy Brown will be flexing his muscles and strutting his stuff.

AUDITORIUM

19.00–19.30
Join Materials Library and their special guests for an introduction to 'Flesh' and the activities on offer.

FORUM

19.45 and 20.45
Reacquaint yourself with the human form (both male and female) in these life-drawing classes. All levels of experience are welcome; sign up at the Forum door for one of a limited number of places.

MEDICINE NOW

18.30–22.00
This is your chance to suture pig skin, dissect a cow's heart, consider skin mimesis and delve into all things fleshy, as well as eating and quite literally pressing a multitude of flesh. Specially created hands-on 'conjectures' are supervised by our expert guests: a plastic surgeon, a surgical nurse, a wax effigy maker, a master butcher, a champion bodybuilder, a biologist and an artist.

MEDICINE MAN

18.30–22.00
You are free to explore the gallery and try your hand in our touch-box conjectures: drilling teeth, sawing bone, freezing fruit and testing elasticity. Materials experts are on hand to answer your questions.

WARNING

Please note: some activities within this event involve the use of sharp tools. Participants are advised to cut with caution and touch with care. All meat products on display are traceable to source and provided by a highly reputable butcher. Vegetarian options are available for some activities upon request.

CREDITS

'Flesh' was devised and created by Martin Conreen, Zoe Laughlin and Mark Miodownik; this is a Materials Library production for Wellcome Collection. Materials Library is a collection of some of the most extraordinary matter on Earth, materials gathered together not only for scientific interest, but also for their ability to fire the imagination and advance conceptualisation.

For more information on the activities of Materials Library, please visit **www.materialslibrary.org.uk**.

materials*Library*

wellcome collection

Wellcome Collection is part of the Wellcome Trust.

Figure D.3: *Flesh* handout; inside, fully unfolded.

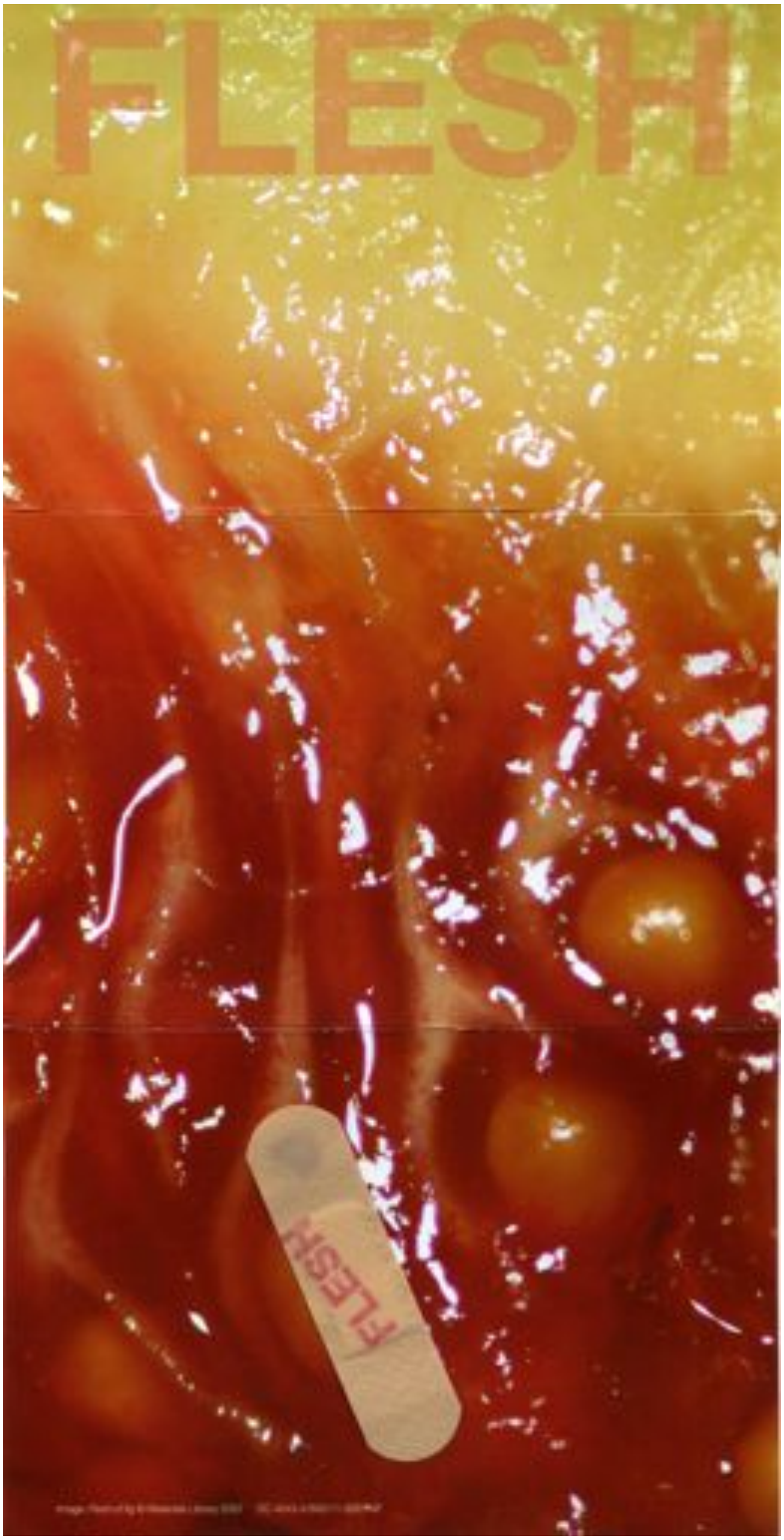
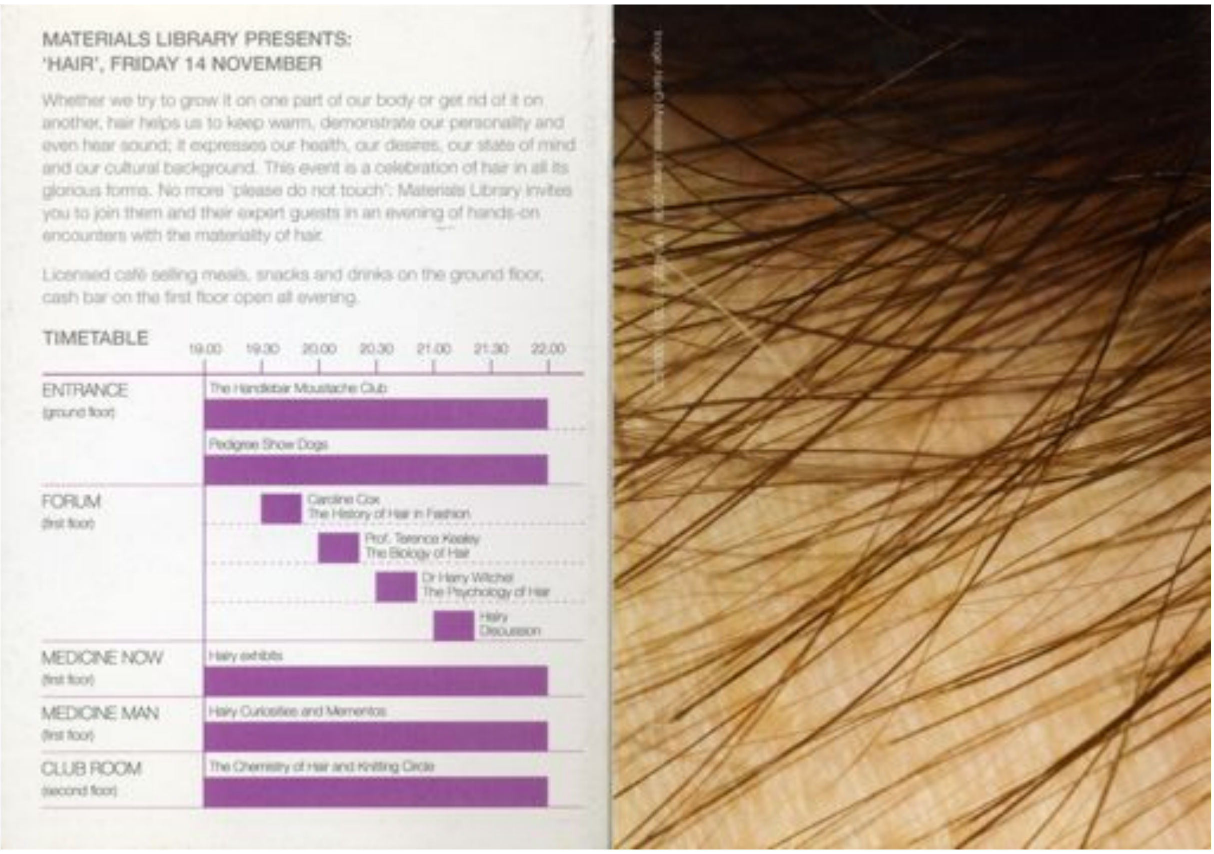


Figure D.4: *Hair* handout; outer image, fully unfolded.

Appendix E

Hair Handout

Figure E.1: *Hair* handout; front.



MATERIALS LIBRARY PRESENTS:
'HAIR', FRIDAY 14 NOVEMBER

Whether we try to grow it on one part of our body or get rid of it on another, hair helps us to keep warm, demonstrate our personality and even hear sound; it expresses our health, our desires, our state of mind and our cultural background. This event is a celebration of hair in all its glorious forms. No more 'please do not touch': Materials Library invites you to join them and their expert guests in an evening of hands-on encounters with the materiality of hair.

Licensed café selling meals, snacks and drinks on the ground floor, cash bar on the first floor open all evening.

TIMETABLE

ENTRANCE (ground floor)
The Handlebar Moustache Club
Pedigree Show Dogs

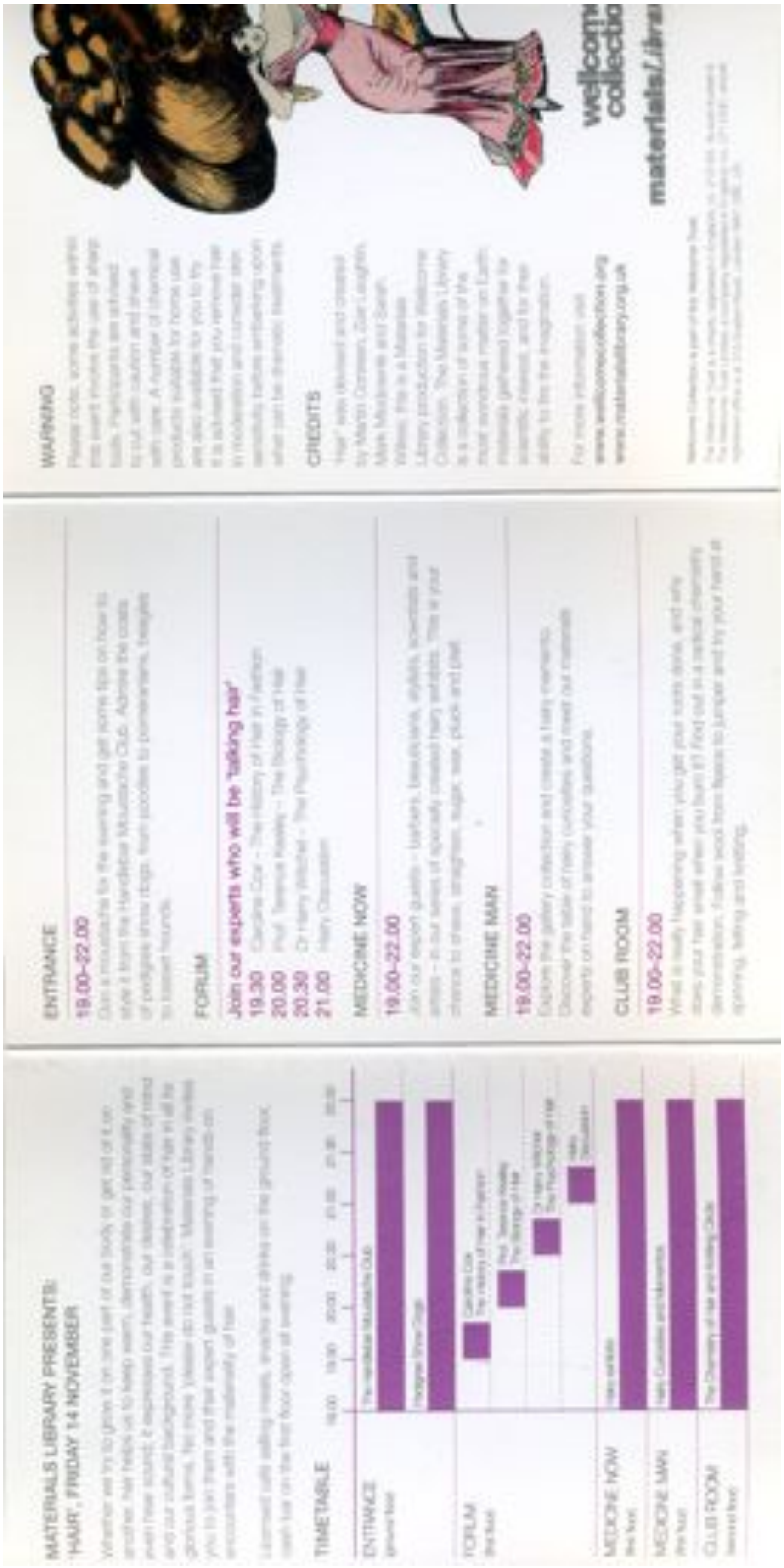
FORUM (first floor)
Caroline Cox
The History of Hair in Fashion
Prof. Terence Kealey
The Biology of Hair
Dr Harry Witchel
The Psychology of Hair
Hairy Discussion

MEDICINE NOW (first floor)
Hairy exhibits

MEDICINE MAN (first floor)
Hairy Curiosities and Mementos

CLUB ROOM (second floor)
The Chemistry of Hair and Knitting Circle

Figure E.2: *Hair* handout; after opening first fold.



MATERIALS LIBRARY PRESENTS:
'HAIR', FRIDAY 14 NOVEMBER

ENTRANCE

19.00–22.00

FORUM

Join our experts who will be 'talking hair'

19.30 Caroline Cox – The History of Hair in Fashion
20.00 Prof. Terence Kealey – The Biology of Hair
20.30 Dr Harry Witchel – The Psychology of Hair
21.00 Hairy Discussion

MEDICINE NOW

19.00–22.00

MEDICINE MAN

19.00–22.00

CLUB ROOM

19.00–22.00

WARNING

CREDITS

For more information visit
www.wellcomecollection.org
www.materialslibrary.org.uk

Figure E.3: *Hair* handout; inside, fully unfolded.

Figure E.4: *Hair* handout; outer image, fully unfolded.

Appendix F

Materials Library Visitor Information

Materials Library visitors 2007

*TOTALED SEPT 1st 2009.
GRAND TOTAL = 460

Architect = 27.

Artist = 53.

MUSICIANS: = 21

67.
Science
Bio = 4
Chem = 6
Phys = 12
Engineer = 28
Materials = 17

Designer = 46

Jeweller = 12

Textiles = 29

(general) Maker etc. = 33

Media = 24

research / consult. + other = 9

OTHER = 22

Student = 117
mainly Art & Design - A level
MA BA + Graduate GCSE

Figure F.1: The form used to log the number of Materials Library visitors and give an indication of their professional background. Information recorded between the start of January 2007 and the end of August 2009.

Materials Library Visitor Statistics

The number of visitors from specific backgrounds:

Architects: 27

Artists: 53

Designers: 46

Jewellers: 12

Makers: 33

Media: 24

Musicians: 21

Other: 22

Research Council/Funder: 9

Scientists: 67

Students: 117

Textiles: 29

Total number of visitors: 460

Total number of subscribers to the Materials Library e-mailing list: 671

Appendix G

Materials Library Field Notes

A representative sample of some of the field notes taken by the author as the participating action researcher (O'Brien, 2010), whilst in the Materials Library with visitors.

Materials Library

Date: 5th Feb 2007
Visitor: Brian Eno !

+ Jane Geerts — his manager l.p.A.

OBSERVATIONS

→ interested in the T.F / Sound of Materials.
↓ making bells for Brian.
↓ "metalic glass"?
as a set of "sonic objects"

ask how sound of materials came about → • Cry of tin! • squeak of aerogel! } did them all.
↓ make T.F.
intense + intensity cubes.

- loved the silly putty.
  * made a dildo.
  loves Blutac — stuck one of the flourescent balls to shelf above

N.B. Koan for bells

- loved the microscope... - bodily investigations. - screen feedback.

As he went from thing to thing, Jane followed with note book, taking everything down.

gave him a tin stick + silly putty to take home.

Figure G.1: Field notes taken on 05-02-07.

Materials Library

Date: April 3. '07
Visitor: Jenny P.

saw talk, came to visit + see more.

OBSERVATIONS

– "why not O?"

↓

looked @ Edgar

↓

damage.

↓

mechanism of form.

hold aerogel cube. → irritant ??
→ glass /

Magnets!
thread from philips!

Sodium Accetate.
↓
super cooling.

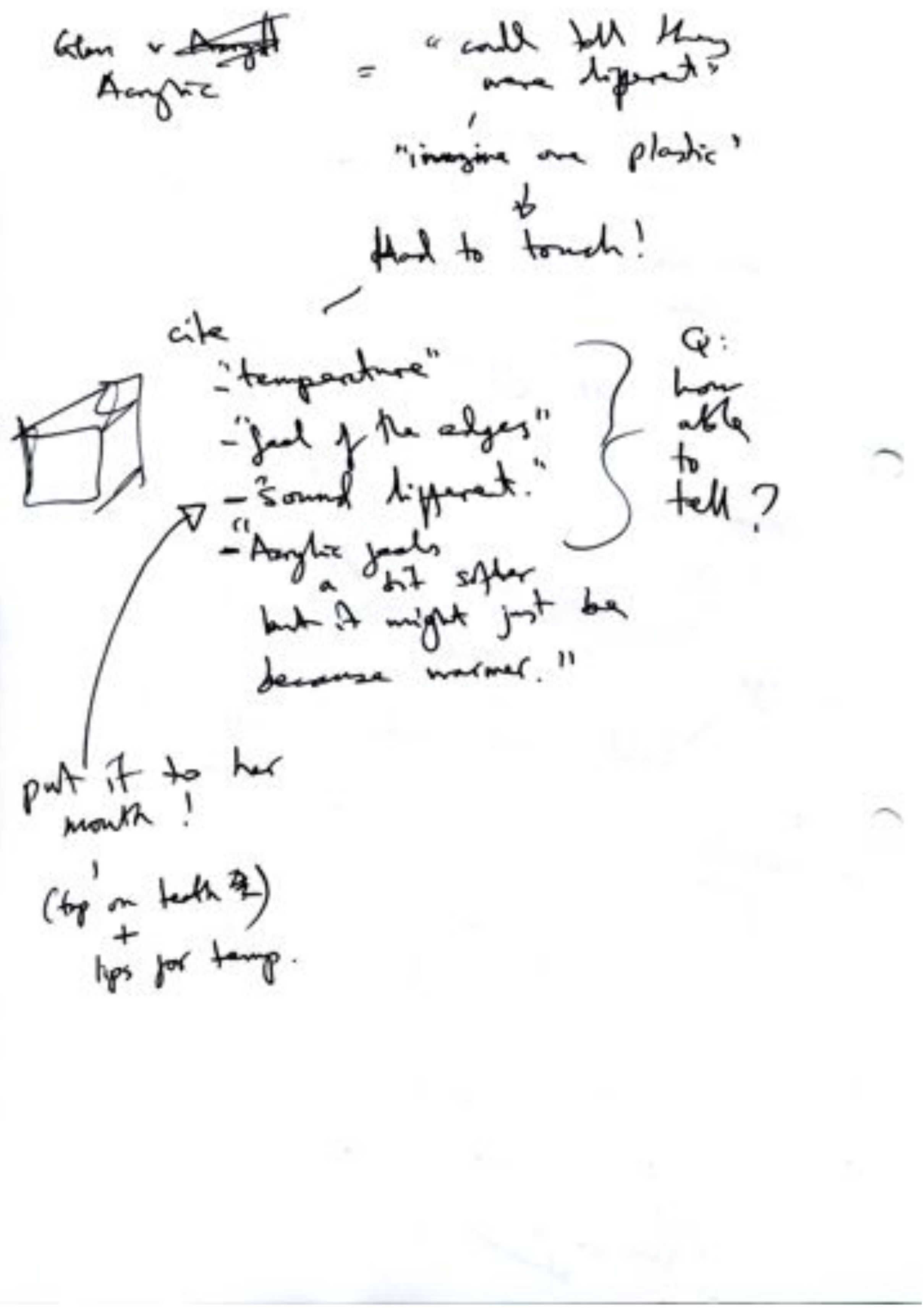
Tungst
✓
Aluminium.

T 1st
A 2nd.
– "shocked"

. "Is this lead"

"This one is aluminium right?!"

Figure G.2: Page 1 of field notes taken on 03-04-07.



Glass v ~~Acrylt~~
Acrylic = "could tell they were different"

"imagine one plastic"

hard to touch!

cite

- "temperature"
- "feel of the edges"
- "sound different."
- "Acrylic feels a bit softer but it might just be because warmer."

Q: how able to tell?

put it to her mouth!

(tap on teeth [illegible])
+
lips for temp.

Figure G.3: Page 2 of field notes taken on 03-04-07.

Materials Library

Date: 29 June 07.
Visitor: James Kennard.

musician/artist.

OBSERVATIONS

- liked the idea of the perpetually rearrangable
ML for x.y.z (insert profession)
eg: Musicians.

- 'materials for musicians.'

- 'materials for politicians'?

what would these be.

- (i) materials that require or impose
- Law + order ?
- idealisms.

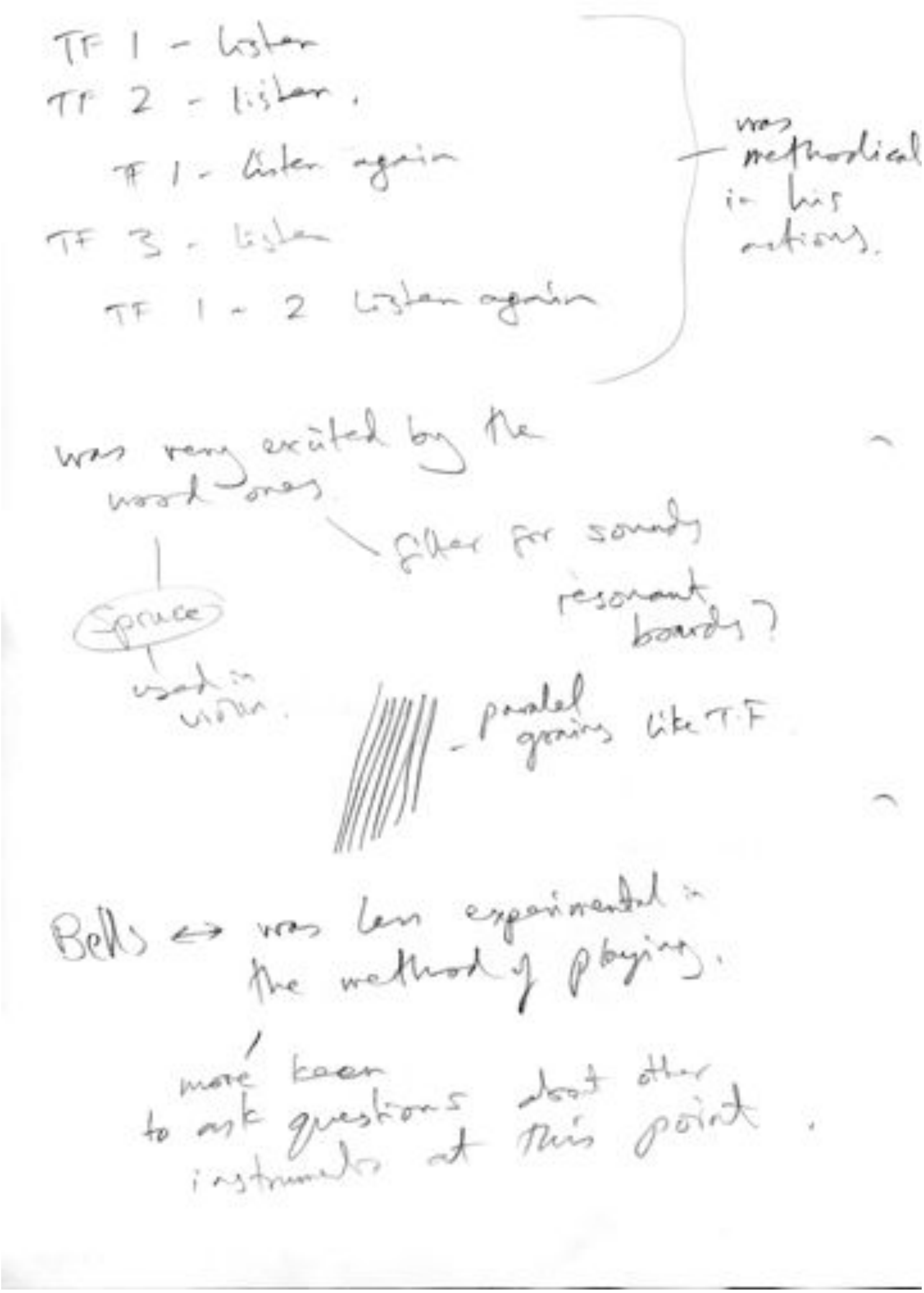
Keen to go through ALL F.F.

could put them in order.

would play them all by pinching + would compare contrast.

Showed me a picture of a special stand he made for his T.T.

Figure G.4: Field notes taken on 29-06-07.

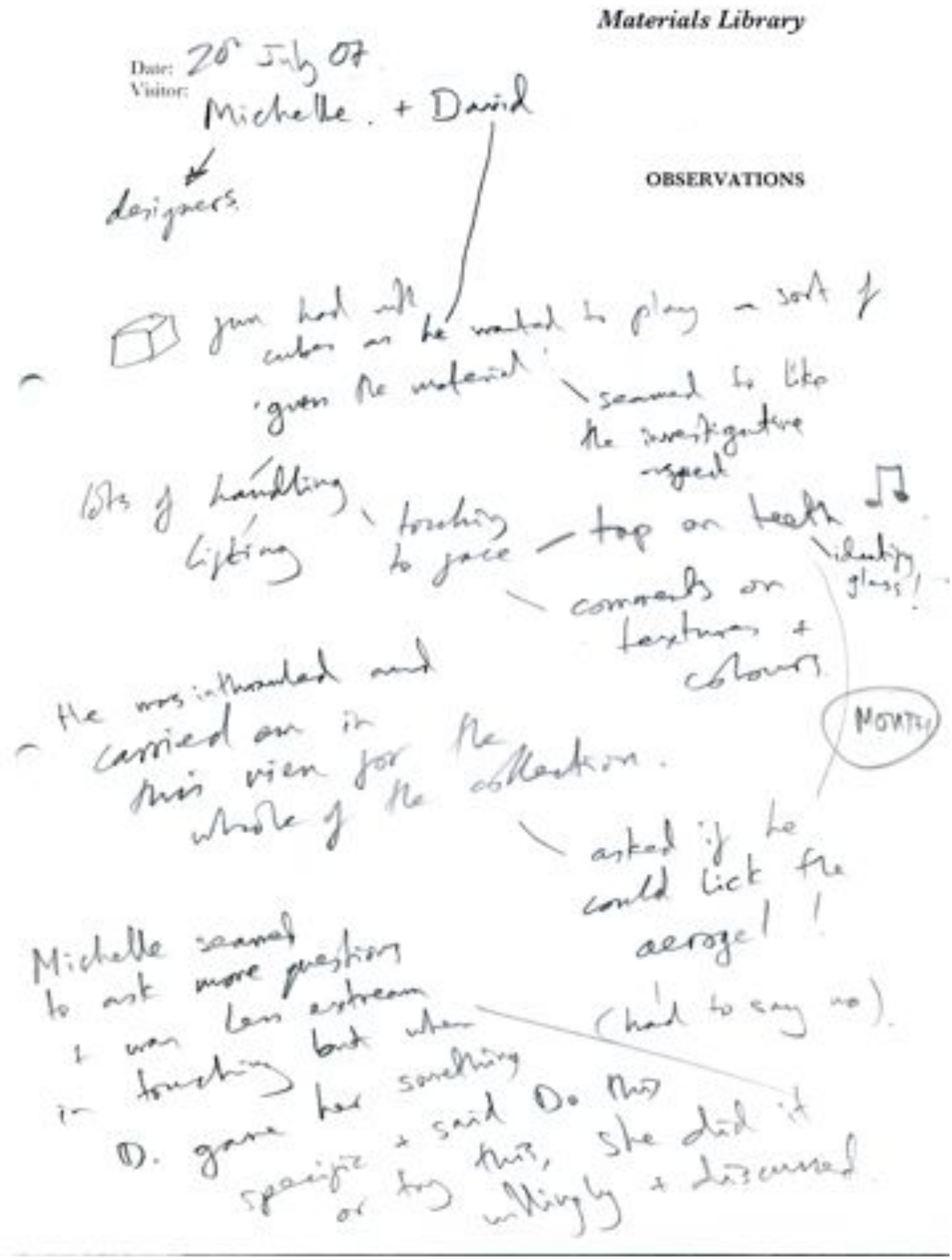


TF 1 - listen
TF 2 - listen.
TF 1 - listen again
TF 3 - listen
TF 1 - 2 listen again
— was methodical in his actions.

was very excited by the wood ones
— filter for sounds
resonant boards?
Spruce
used in violin.
— parallel grains like T.F

Bells ↔ was less experimental in the method of playing.
more keen to ask questions about other instruments at this point.

Figure G.5: Field notes taken on 29-06-07.



Materials Library

Date: 20 July 07
Visitor: Michelle. + David

designers

OBSERVATIONS

fun had with cubes as he wanted to play – sort of 'given the material'

seemed to like the investigative aspect

lots of handling lifting

touching to face – tap on teeth ♫

identify glass!

comments on textures + colours

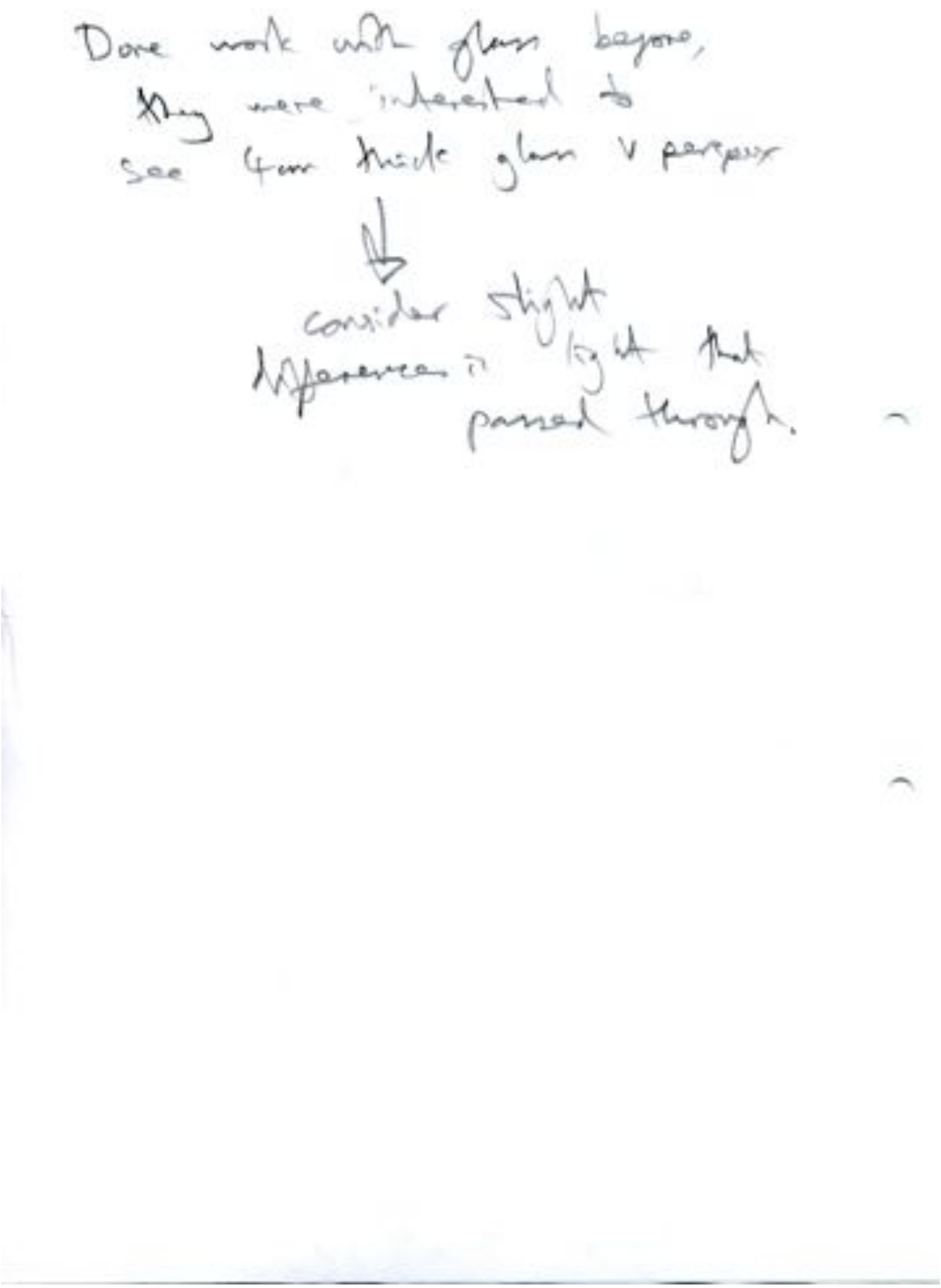
MOUTH

He was enthralled and carried on in this vein for the whole of the collection.

asked if he could lick the aerogel!! (had to say no).

Michelle seemed to ask more questions + was less extreme in touching but when D. gave her something specific + said Do this or try this, she did it willingly + discussed

Figure G.6: Page 1 of field notes taken on 20-07-07.

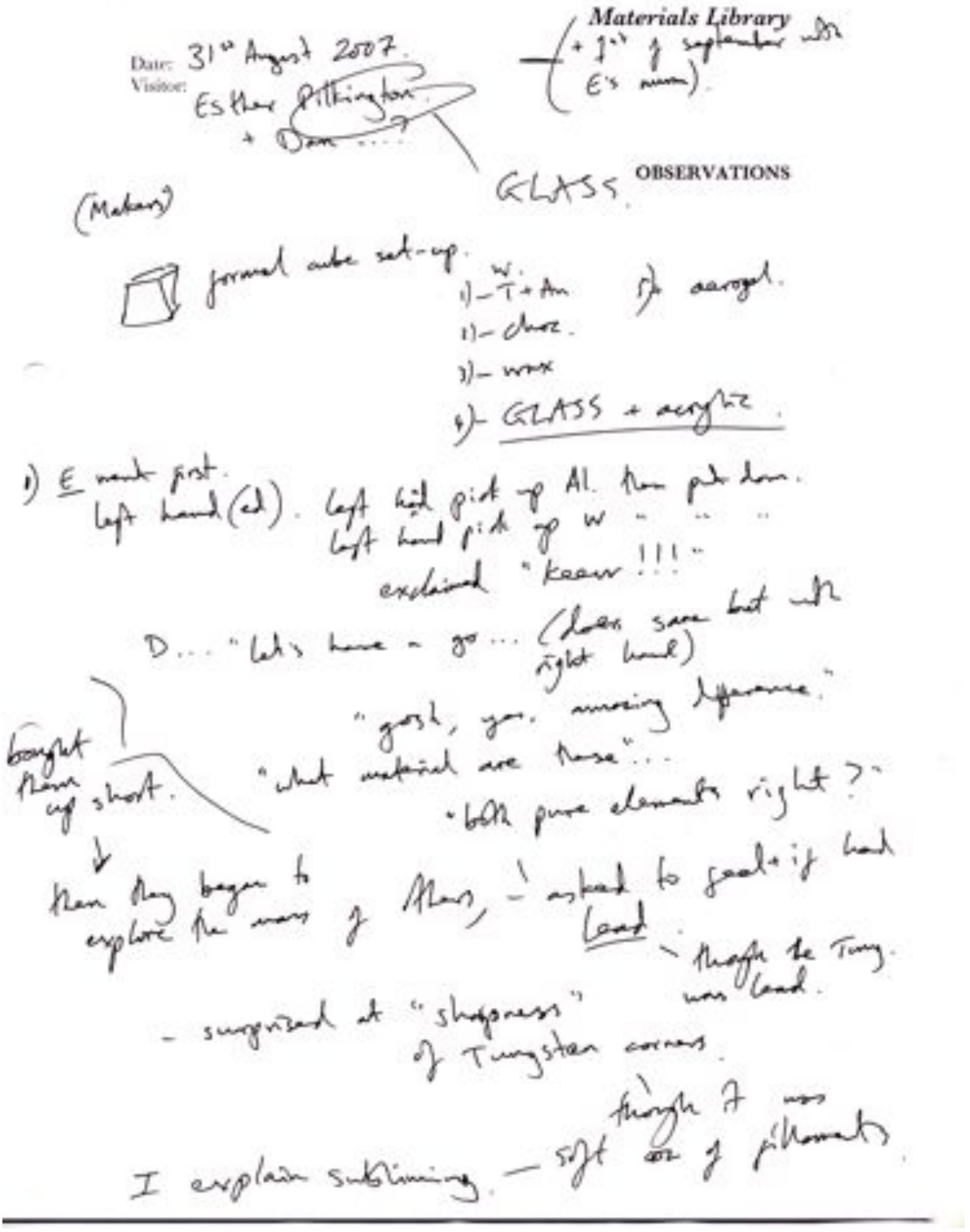


Done work with glass before,
they were interested to
see 4mm thick glass v perspex

⇓

consider slight
difference in light that
passed through.

Figure G.7: Page 2 of field notes taken on 20-07-07.



Materials Library
(+ 1st of September with E's mum).

Date: 31st August 2007.
Visitor: Esther Pilkington
+ Dan ....

GLASS **OBSERVATIONS**

(Makers)

formal cube set-up.

W.
1) – T + Au 5) aerogel.
2) – cheese.
3) – wax
4) – GLASS + acrylic.

1) E went first.
left hand (ed). left hand pick up Al. then put down.
left hand pick up W " " "
exclaimed "keeaw!!!"

D... "let's have a go... (does same but with right hand)

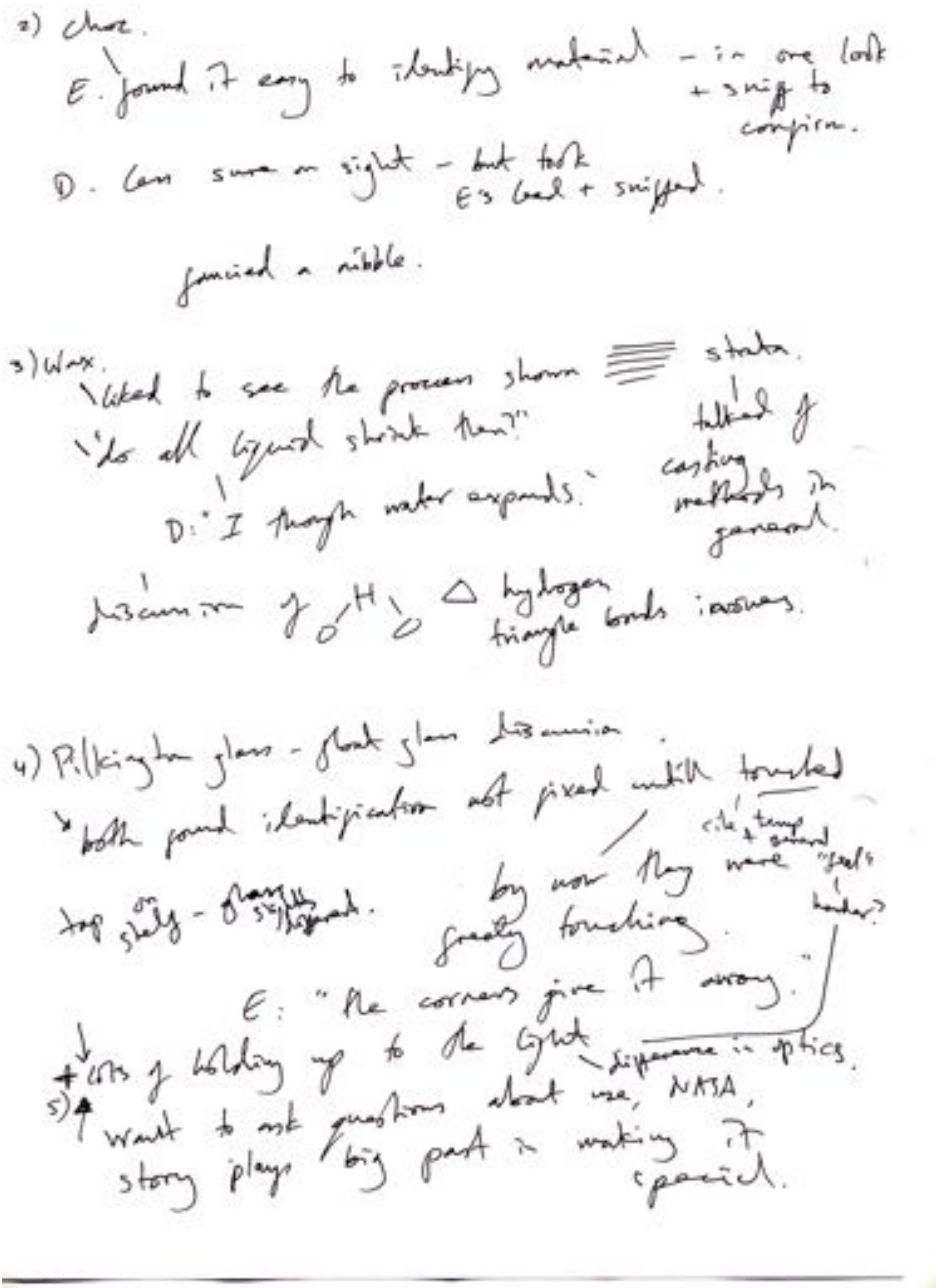
"gosh, yes. amazing difference."
"what material are these"...
"both pure elements right?"

brought them up short.
↓
then they began to explore the mass of them, – asked to feel if had lead. – thought the Tung. was lead.

– surprised at "sharpness" of Tungsten corners.

I explain sublimining. – soft though it was use of filaments.

Figure G.8: Page 1 of field notes taken on 31-08-07.

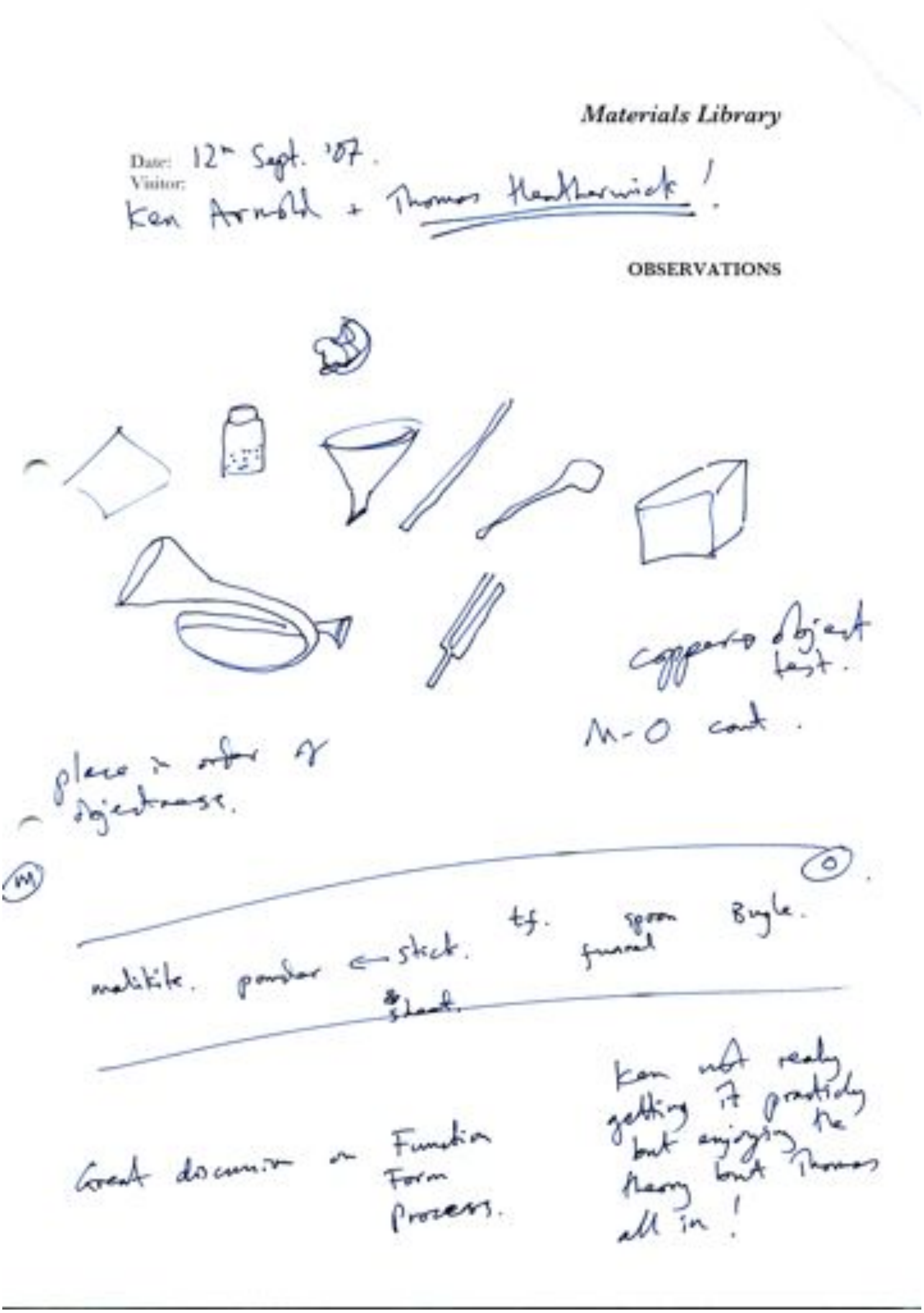


2) choc.
E. found it easy to identify material – in one look + sniff to confirm.
D. Less sure on sight – but took E's lead + sniffed.
fancied a nibble.

3) Wax.
liked to see the process shown ≡ strata.
"do all liquid shrink then?"
D: "I thought water expands."
talked of casting methods in general.
discussion of H_2O △ hydrogen triangle bonds in water.

4) Pilkington glass – float glass discussion.
→ both found identification not fixed until touched
top on shelf – [illegible].
by now they were greatly touching.
cite temp + sound
"feel"
harder?
E: "the corners give it away."
+ lots of holding up to the light – difference in optics.
5) want to ask questions about use, NASA,
story plays big part in making it special.

Figure G.9: Page 2 of field notes taken on 31-08-07.



Materials Library

Date: 12th Sept. '07.
Visitor:
Ken Arnold + Thomas Heatherwick!.

OBSERVATIONS

coppero object test.

M-O cont.

place in order of objectness.

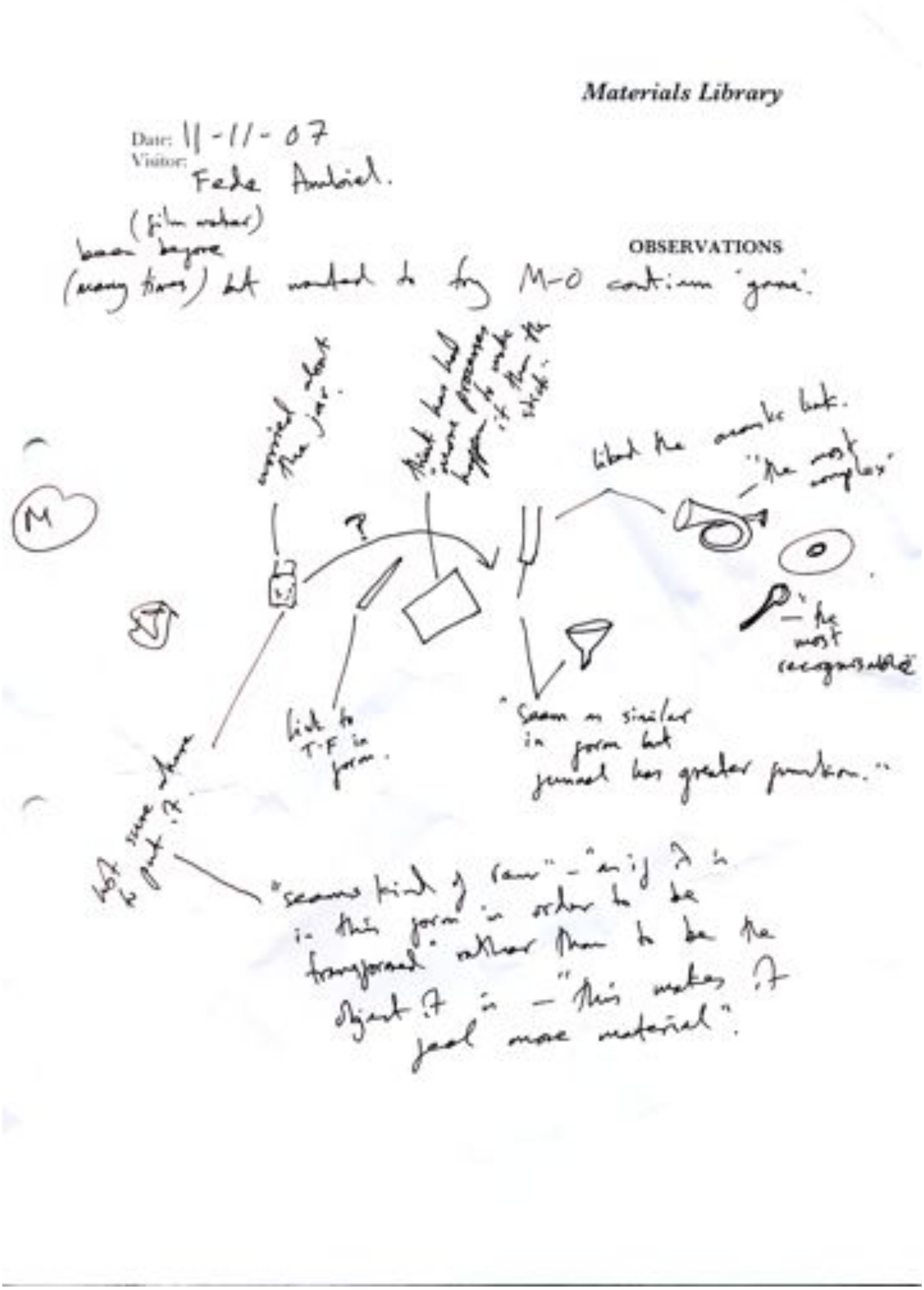
ⓜ ⓞ.

malikite. powder ← stick. & sheet. tf. spoon funnel Bugle.

Great discussion on Function Form Process.

Ken not really getting it practically but enjoying the theory but Thomas all in!

Figure G.10: Field notes taken on 12-09-07.



Materials Library

Date: 11-11-07
Visitor: Fede Andrial.
(film maker)

OBSERVATIONS

been before (many times) but wanted to try M-O continuum 'game'.

[illegible] the jar look.

[illegible] how had some processes happen to make the thick.

liked the acoustic link.

"the most complex"

"the most recognisable"

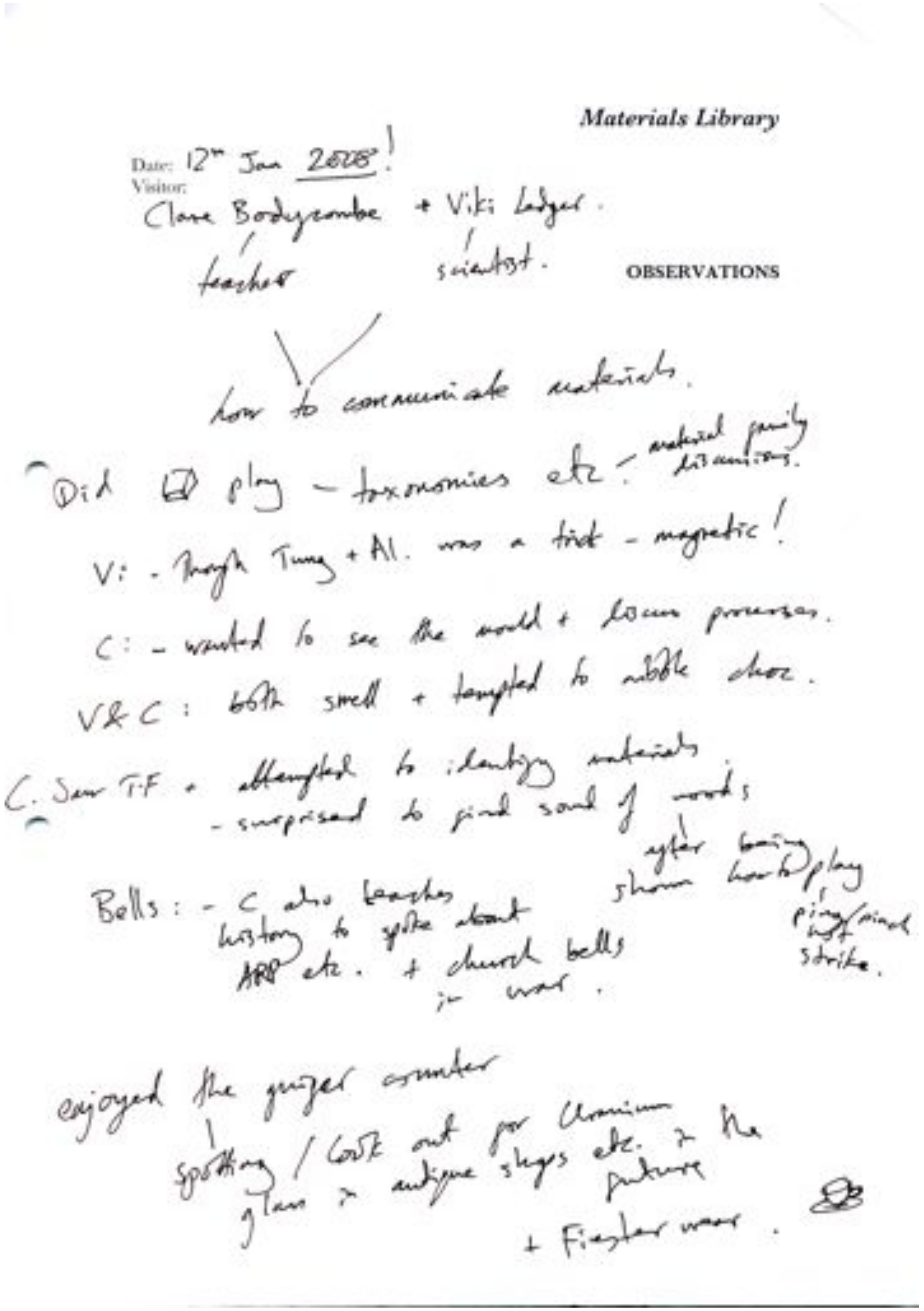
link to T-F in form.

"Seem as similar in form but funnel has greater function."

but seem shown to put it.

"seems kind of raw" – "as if it is in this form in order to be transformed" rather than to be the object it is – "this makes it feel more material".

Figure G.11: Field notes taken on 11-11-07.



Materials Library

Date: 12th Jan 2008!
Visitor:
Clare Bodyscombe + Viki Ledger.
teacher scientist.

OBSERVATIONS

how to communicate materials.

Did LD play – taxonomies etc. – material family divisions.

V: - Tough Tung + Al. was a trick – magnetic!

C: – wanted to see the world + loom processes.

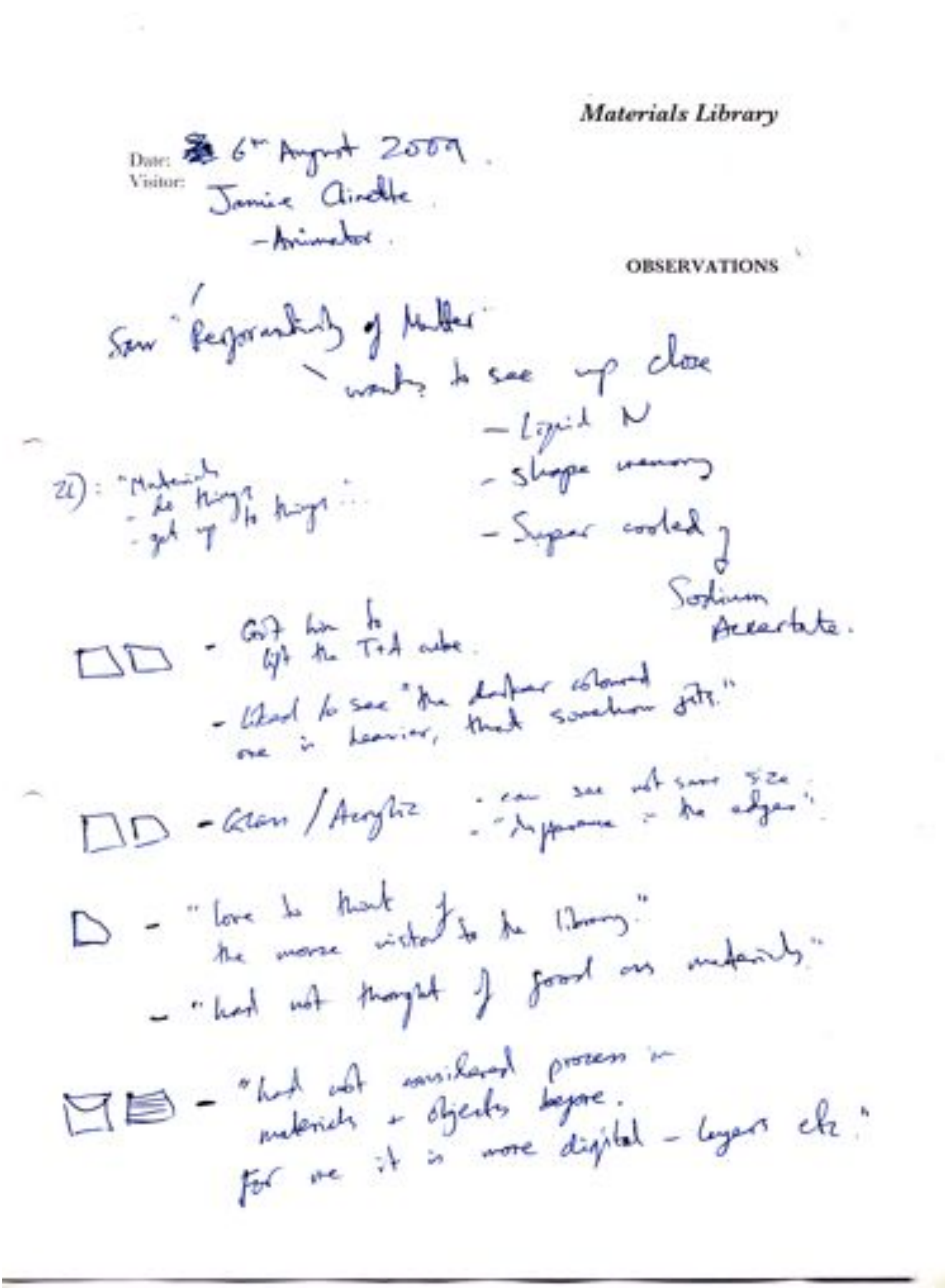
V&C: both smell + tempted to nibble choc.

C. Saw T.F + attempted to identify materials.
- surprised to find sound of woods after being shown how to play ping/ring not strike.

Bells: – C also teaches history to spoke about ARP etc. + church bells in war.

enjoyed the geiger counter
spotting / look out for Uranium glass in antique shops etc. in the future
+ Fiesta ware.

Figure G.12: Field notes taken on 12-01-08.



Materials Library

Date: 6th August 2009.
Visitor: Jamie Aindtle
- Animator.

OBSERVATIONS

Saw "Responsivity of Matter"
wants to see up close
- Liquid N
- shape memory
- Super cooled
Sodium Acetate.

2i): "Materials
- the things
- get up to things"

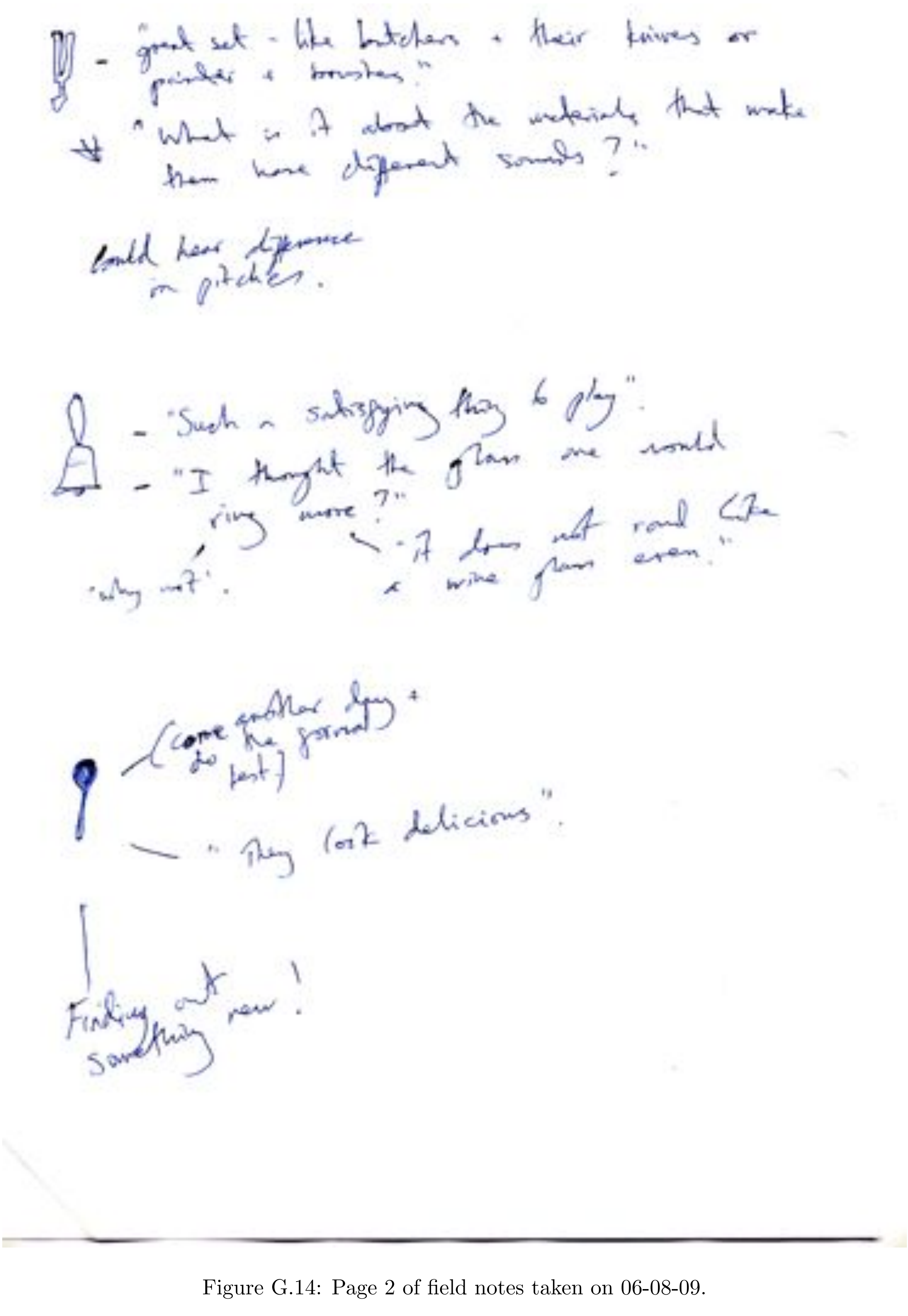
- Got him to lift the T+A cube.
- Liked to see "the darker coloured one is heavier, that somehow fits."

- Glass / Acrylic
- can see not same size.
- "Appearance - the edges".

- "love to think of the more visitors to the library."
- "had not thought of food as materials."

- "had not considered process in materials + objects before.
For me it is more digital - layers etc."

Figure G.13: Page 1 of field notes taken on 06-08-09.



- "great set - like butchers + their knives or painters + brushes."
- "What is it about the materials that make them have different sounds?"

Could hear difference in pitches.

- "Such a satisfying thing to play".
- "I thought the glass one would ring more?"

'why not'.

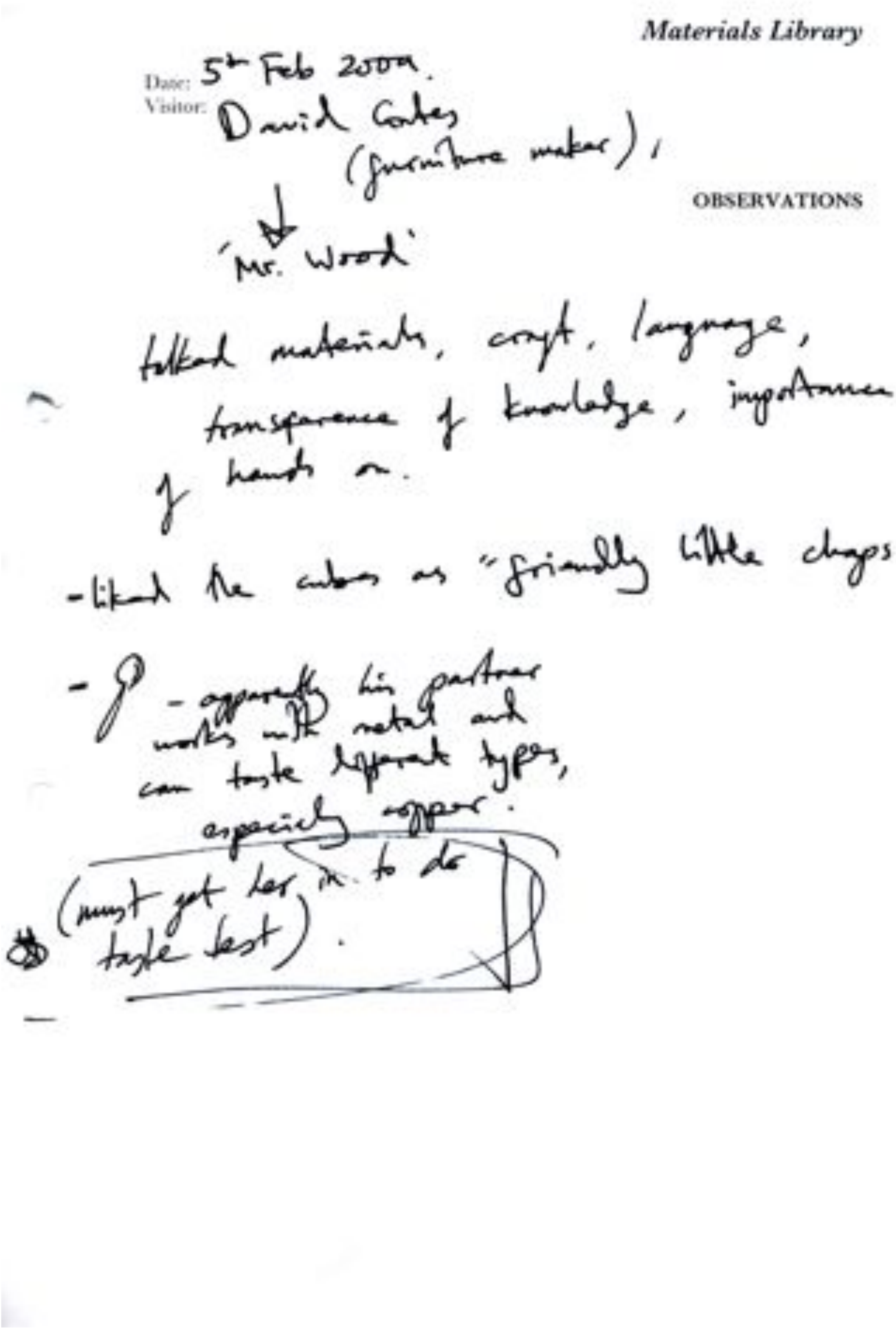
- "it does not sound like a wine glass even."

(come another day + do the [illegible] test)

- "They look delicious".

Finding out something new!

Figure G.14: Page 2 of field notes taken on 06-08-09.



Materials Library

Date: 5th Feb 2009.
Visitor: David Cotes
(furniture maker),
↓
'Mr. Wood'

OBSERVATIONS

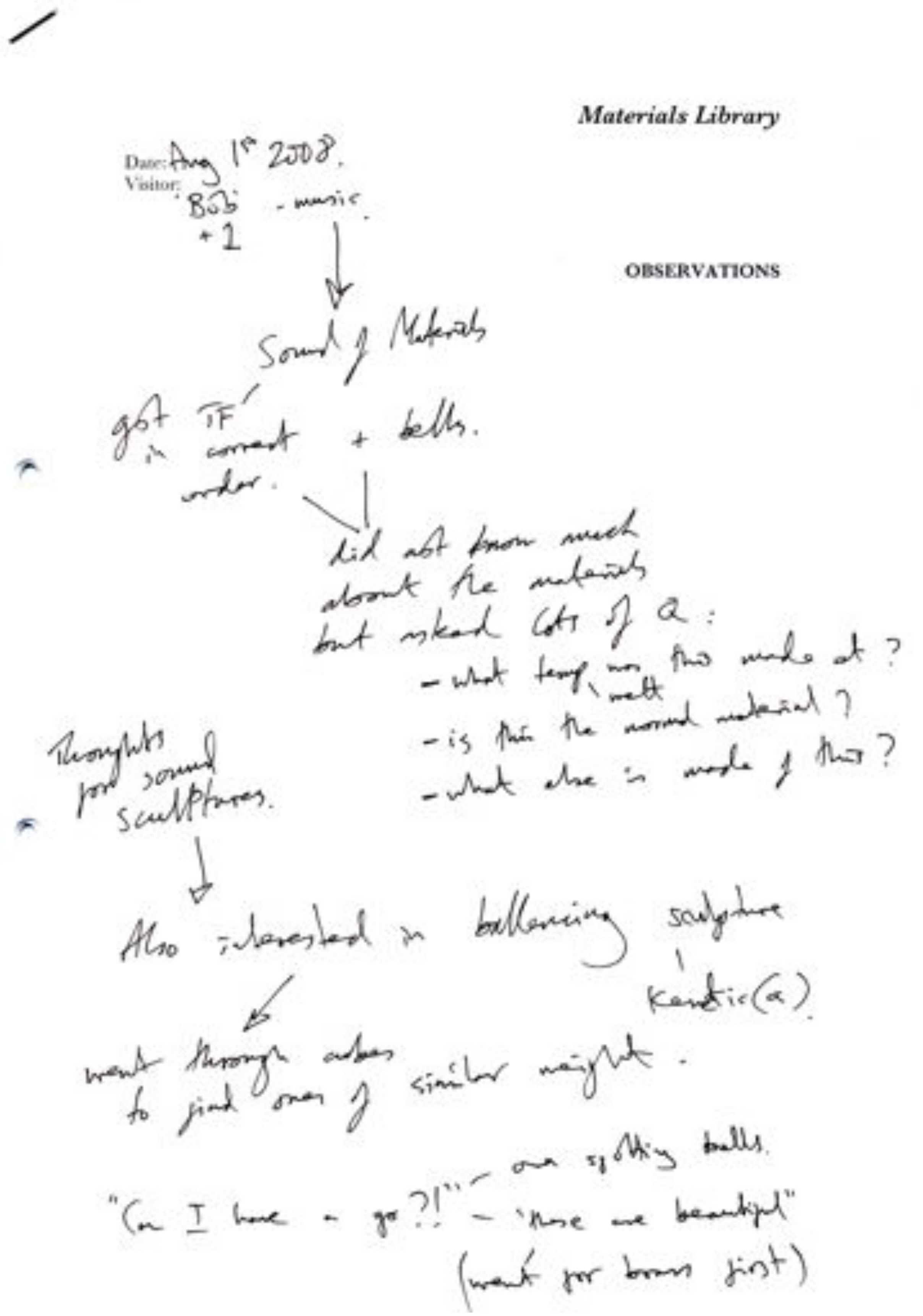
talked materials, craft, language, transparency of knowledge, importance of hands on.

- liked the cubes as "friendly little chaps"

- - apparently his partner works with metal and can taste different types, especially copper.

(must get her in to do taste test).

Figure G.15: Field notes taken on 05-02-09.



Materials Library

Date: Aug 1st 2008.
Visitor: Bob - music.
+1

OBSERVATIONS

Sound of Materials

got TF in correct order + bells.

did not know much about the materials but asked lots of Q:
- what temp, melt was this made at?
- is this the normal material?
- what else is made of this?

Thoughts for sound sculptures.

Also interested in balancing sculpture
Kinetic(a).

went through cubes to find ones of similar weight.

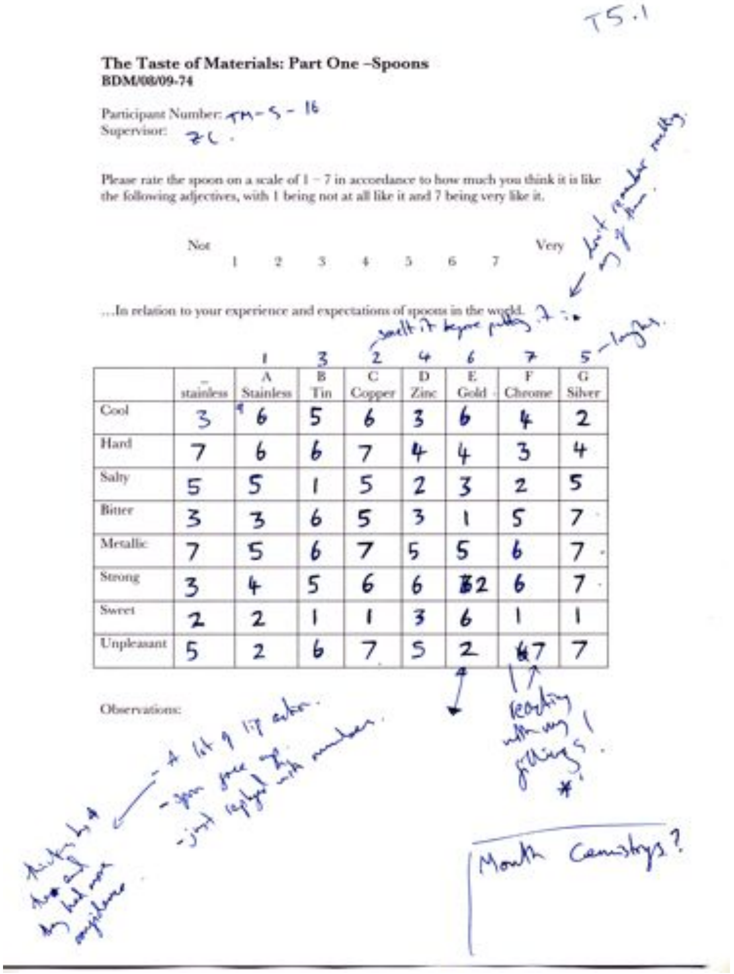
"Can I have a go?!" – one spotting balls.
– "these are beautiful"
(went for brass first)

Figure G.16: Field notes taken on 01-08-08.

Appendix H

Spoons Field Notes

A representative sample of some of the observational annotations made by the experimental supervisor during the spoon taste tests in chapter 8. .



TS.1

The Taste of Materials: Part One –Spoons
BDM/08/09-74

Participant Number: TM-S-16
Supervisor: ZC.

Please rate the spoon on a scale of 1 – 7 in accordance to how much you think it is like the following adjectives, with 1 being not at all like it and 7 being very like it.

Not 1 2 3 4 5 6 7 Very

…In relation to your experience and expectations of spoons in the world.

smelt it before putting ? in

[illegible]

5 – laughs.

		1	3	2	4	6	7	5
	– stainless	A Stainless	B Tin	C Copper	D Zinc	E Gold	F Chrome	G Silver
Cool	3	6	5	6	3	6	4	2
Hard	7	6	6	7	4	4	3	4
Salty	5	5	1	5	2	3	2	5
Bitter	3	3	6	5	3	1	5	7
Metallic	7	5	6	7	5	5	6	7
Strong	3	4	5	6	6	~~3~~2	6	7
Sweet	2	2	1	1	3	6	1	1
Unpleasant	5	2	6	7	5	2	~~6~~7	7

Observations:

- A lot of lip action.
- spoon goes up [illegible]
- just replyed with number.

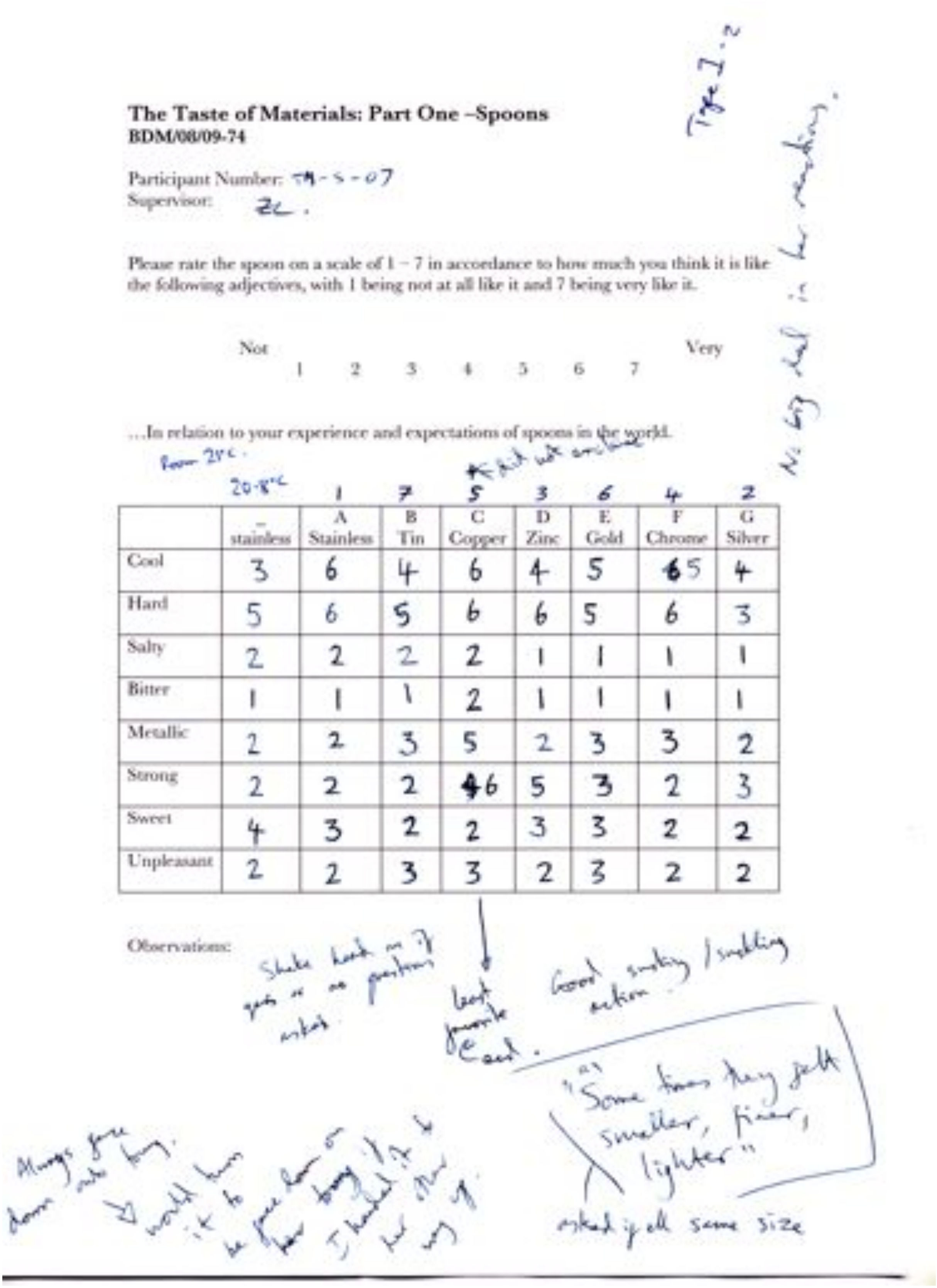
[illegible]

reacting with my fillings!

*

Mouth Chemistry?

Figure H.1: Formal rating of spoons by participants written down by the experiment supervisor and annotated by her observations and filed notes for participant TM-S-16.



The Taste of Materials: Part One –Spoons
BDM/08/09-74

Participant Number: TM-S-07
Supervisor: ZC.

Type I.2

No big deal in her ranking.

Please rate the spoon on a scale of 1 – 7 in accordance to how much you think it is like the following adjectives, with 1 being not at all like it and 7 being very like it.

Not 1 2 3 4 5 6 7 Very

…In relation to your experience and expectations of spoons in the world.

Room 21°C.

20.8°C

*But not [illegible]

		1	7	5	3	6	4	2
	– stainless	A Stainless	B Tin	C Copper	D Zinc	E Gold	F Chrome	G Silver
Cool	3	6	4	6	4	5	~~6~~5	4
Hard	5	6	5	6	6	5	6	3
Salty	2	2	2	2	1	1	1	1
Bitter	1	1	1	2	1	1	1	1
Metallic	2	2	3	5	2	3	3	2
Strong	2	2	2	~~4~~6	5	3	2	3
Sweet	4	3	2	2	3	3	2	2
Unpleasant	2	2	3	3	2	3	2	2

Observations:

Shake head on 7 gets it on position asked.

best favourite C and.

Good smoking / smelling action.

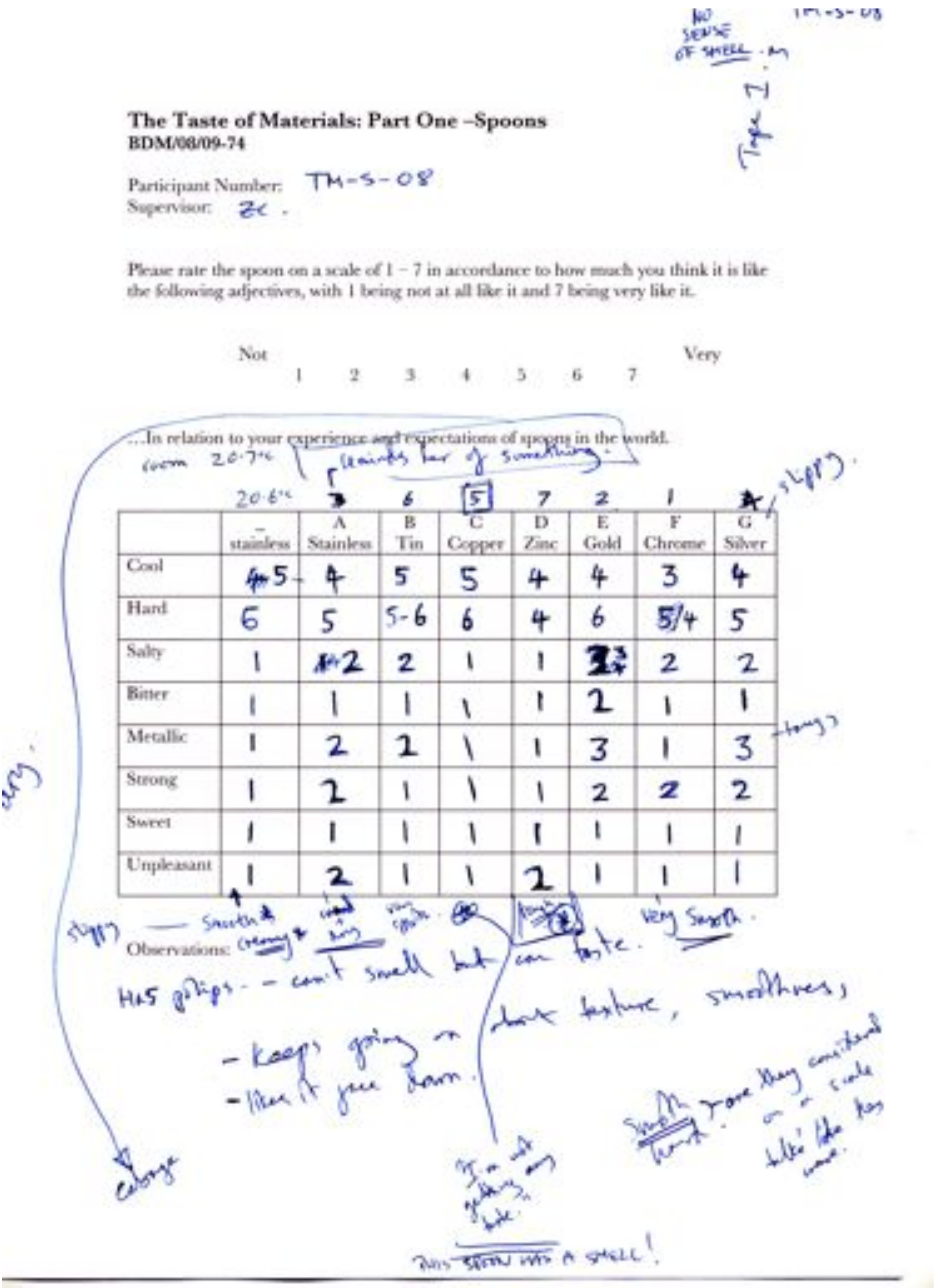
as "Some times they felt smaller, finer, lighter"

asked if all same size

Always goes down into tasting.

[illegible]

Figure H.2: Formal rating of spoons by participants written down by the experiment supervisor and annotated by her observations and filed notes for participant TM-S-07.



NO SENSE OF SMELL. [illegible]

TM-S-08

Tape I

The Taste of Materials: Part One –Spoons
BDM/08/09-74

Participant Number: TM-S-08
Supervisor: ZC.

Please rate the spoon on a scale of 1 – 7 in accordance to how much you think it is like the following adjectives, with 1 being not at all like it and 7 being very like it.

Not 1 2 3 4 5 6 7 Very

…In relation to your experience and expectations of spoons in the world.

room 20.7°c reminds her of something.

	20.6°c	3	6	5	7	2	1	4
	– stainless	A Stainless	B Tin	C Copper	D Zinc	E Gold	F Chrome	G Silver
Cool	~~4~~ 5	4	5	5	4	4	3	4
Hard	6	5	5-6	6	4	6	5/4	5
Salty	1	~~1~~ 2	2	1	1	3	2	2
Bitter	1	1	1	1	1	2	1	1
Metallic	1	2	2	1	1	3	1	3
Strong	1	2	1	1	1	2	2	2
Sweet	1	1	1	1	1	1	1	1
Unpleasant	1	2	1	1	2	1	1	1

slippy. tongs

Observations: slippy — smooth & creamy cold & big [illegible] [illegible] very smooth.

Has grips. — can't smell but can taste.

don't texture, smoothness,

– keeps going on

– likes it going down.

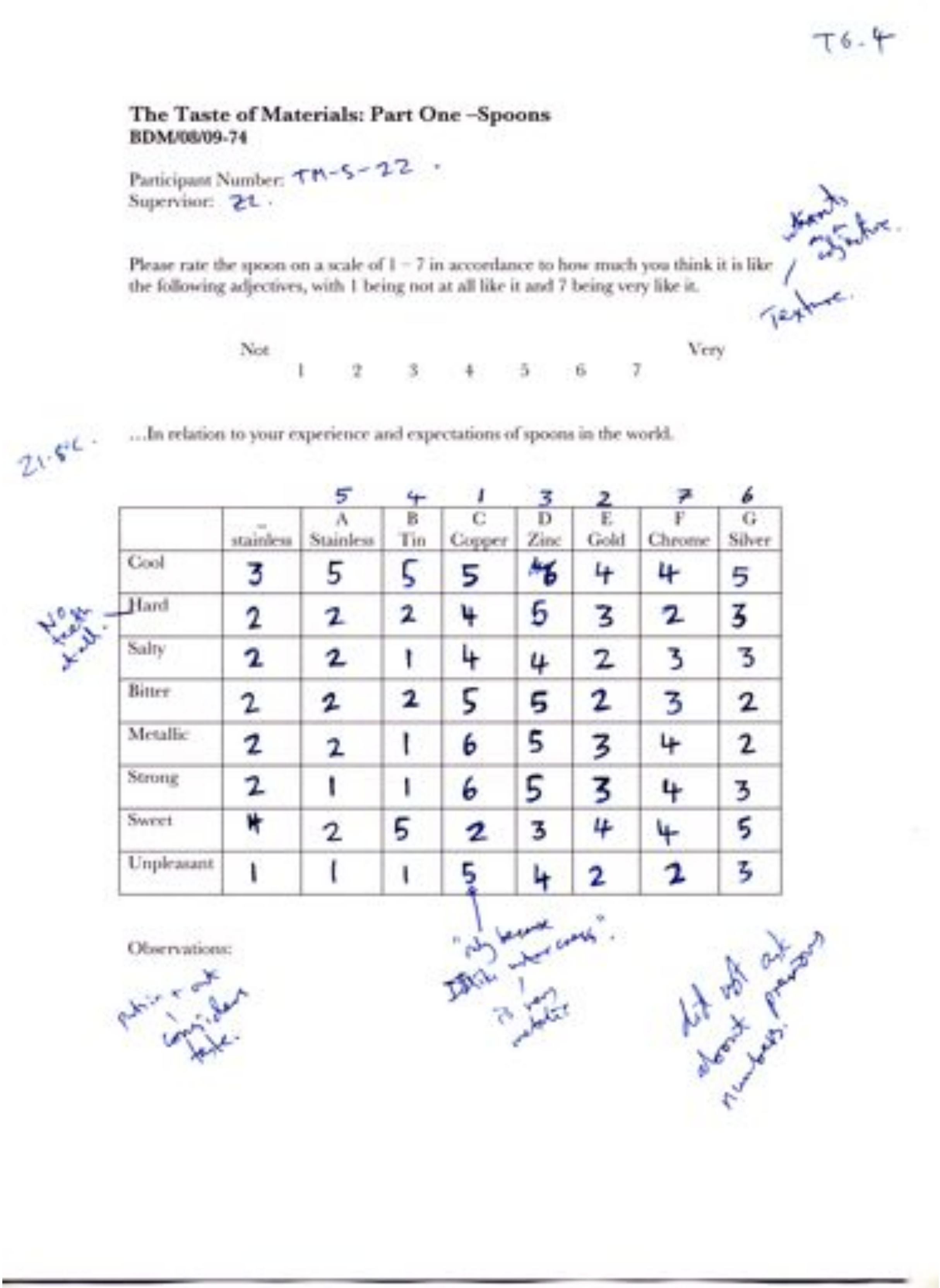
very. change

I'm not getting any taste.

smooth more they considered on a scale like the has [illegible]

This spoon has a smell!

Figure H.3: Formal rating of spoons by participants written down by the experiment supervisor and annotated by her observations and filed notes for participant TM-S-08.



T6-4

The Taste of Materials: Part One –Spoons
BDM/08/09-74

Participant Number: TM-S-22.
Supervisor: ZL.

Please rate the spoon on a scale of 1 – 7 in accordance to how much you think it is like the following adjectives, with 1 being not at all like it and 7 being very like it.

stands adjective. / Texture.

Not							Very
	1	2	3	4	5	6	7

21.8°C.

…In relation to your experience and expectations of spoons in the world.

		5	4	1	3	2	7	6
	– stainless	A Stainless	B Tin	C Copper	D Zinc	E Gold	F Chrome	G Silver
Cool	3	5	5	5	~~4~~6	4	4	5
Hard	2	2	2	4	5	3	2	3
Salty	2	2	1	4	4	2	3	3
Bitter	2	2	2	5	5	2	3	2
Metallic	2	2	1	6	5	3	4	2
Strong	2	1	1	6	5	3	4	3
Sweet	4	2	5	2	3	4	4	5
Unpleasant	1	1	1	5	4	2	2	3

Not that hard.

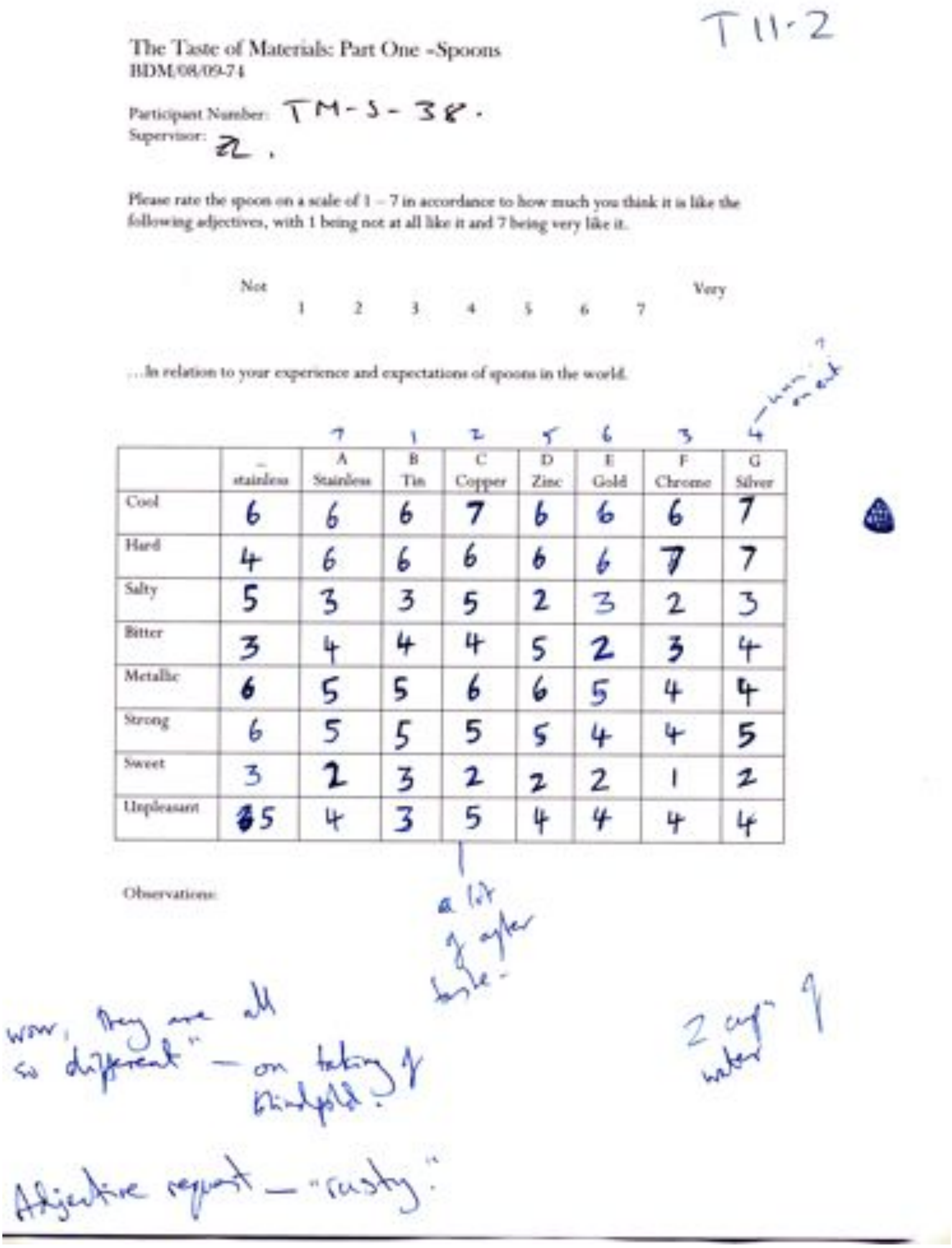
Observations:

Picking it up / considers taste.

"only because [illegible] where comes". / [illegible] very metallic

bit off at / doubt previous numbers.

Figure H.4: Formal rating of spoons by participants written down by the experiment supervisor and annotated by her observations and filed notes for participant TM-S-22.



T 11-2

The Taste of Materials: Part One -Spoons
BDM/08/09-74

Participant Number: TM-S-38.
Supervisor: ZL.

Please rate the spoon on a scale of 1 – 7 in accordance to how much you think it is like the following adjectives, with 1 being not at all like it and 7 being very like it.

Not	1	2	3	4	5	6	7	Very

…In relation to your experience and expectations of spoons in the world.

		7	1	2	5	6	3	4
	– stainless	A Stainless	B Tin	C Copper	D Zinc	E Gold	F Chrome	G Silver
Cool	6	6	6	7	6	6	6	7
Hard	4	6	6	6	6	6	7	7
Salty	5	3	3	5	2	3	2	3
Bitter	3	4	4	4	5	2	3	4
Metallic	6	5	5	6	6	5	4	4
Strong	6	5	5	5	5	4	4	5
Sweet	3	2	3	2	2	2	1	2
Unpleasant	~~3~~5	4	3	5	4	4	4	4

[illegible] ?

Observations:

a lot of after taste.

"wow, they are all so different" — on taking of blindfold?

2 cup of water ?

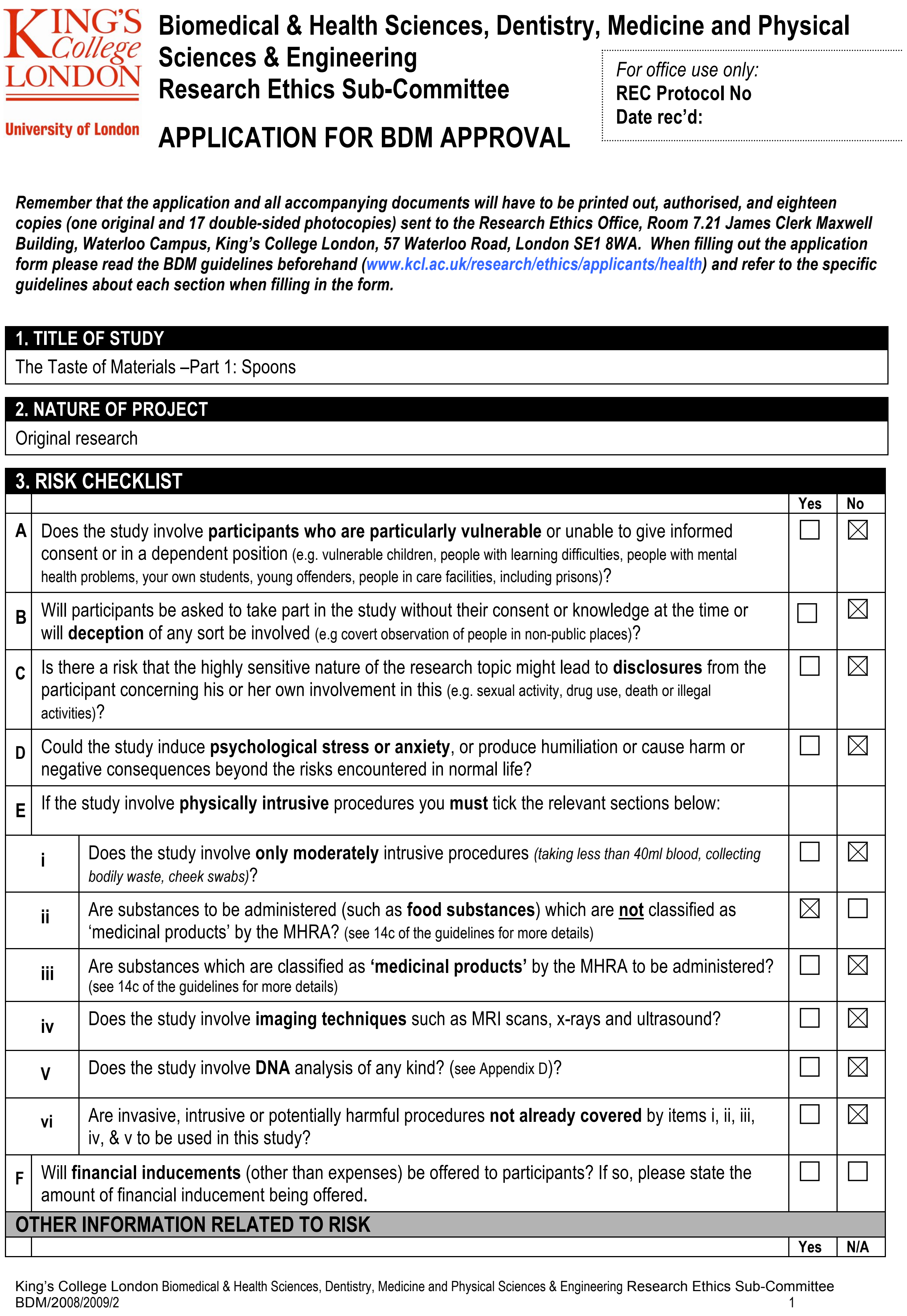
Adjective request — "rusty".

Figure H.5: Formal rating of spoons by participants written down by the experiment supervisor and annotated by her observations and filed notes for participant TM-S-38.

Appendix I

Ethics Committee Submission

The following appendix is a record of the form submitted to the ethics committee in order to approve the testing of the taste of materials using the spoons, applicable to the work of chapter 8. Figures I.11 and I.12 show the Consents form signed by every participant before commencing the experiment.



KING'S College LONDON
University of London

Biomedical & Health Sciences, Dentistry, Medicine and Physical Sciences & Engineering Research Ethics Sub-Committee

APPLICATION FOR BDM APPROVAL

For office use only:
REC Protocol No
Date rec'd:

Remember that the application and all accompanying documents will have to be printed out, authorised, and eighteen copies (one original and 17 double-sided photocopies) sent to the Research Ethics Office, Room 7.21 James Clerk Maxwell Building, Waterloo Campus, King's College London, 57 Waterloo Road, London SE1 8WA. When filling out the application form please read the BDM guidelines beforehand (www.kcl.ac.uk/research/ethics/applicants/health) and refer to the specific guidelines about each section when filling in the form.

1. TITLE OF STUDY

The Taste of Materials –Part 1: Spoons

2. NATURE OF PROJECT

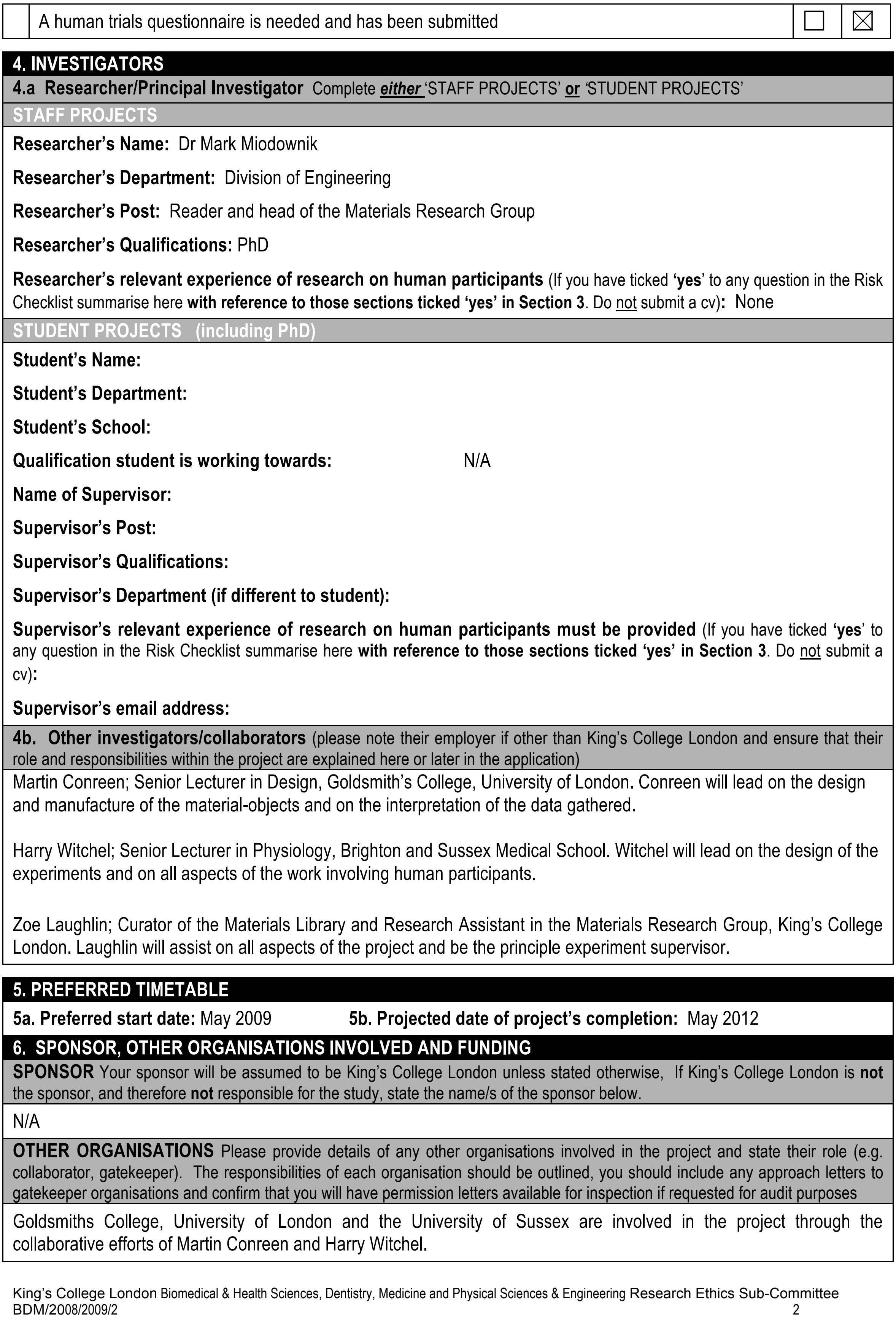
Original research

3. RISK CHECKLIST

		Yes	No
A	Does the study involve **participants who are particularly vulnerable** or unable to give informed consent or in a dependent position (e.g. vulnerable children, people with learning difficulties, people with mental health problems, your own students, young offenders, people in care facilities, including prisons)?	☐	☒
B	Will participants be asked to take part in the study without their consent or knowledge at the time or will **deception** of any sort be involved (e.g covert observation of people in non-public places)?	☐	☒
C	Is there a risk that the highly sensitive nature of the research topic might lead to **disclosures** from the participant concerning his or her own involvement in this (e.g. sexual activity, drug use, death or illegal activities)?	☐	☒
D	Could the study induce **psychological stress or anxiety**, or produce humiliation or cause harm or negative consequences beyond the risks encountered in normal life?	☐	☒
E	If the study involve **physically intrusive** procedures you **must** tick the relevant sections below:		
i	Does the study involve **only moderately** intrusive procedures *(taking less than 40ml blood, collecting bodily waste, cheek swabs)*?	☐	☒
ii	Are substances to be administered (such as **food substances**) which are **not** classified as 'medicinal products' by the MHRA? (see 14c of the guidelines for more details)	☒	☐
iii	Are substances which are classified as **'medicinal products'** by the MHRA to be administered? (see 14c of the guidelines for more details)	☐	☒
iv	Does the study involve **imaging techniques** such as MRI scans, x-rays and ultrasound?	☐	☒
V	Does the study involve **DNA** analysis of any kind? (see Appendix D)?	☐	☒
vi	Are invasive, intrusive or potentially harmful procedures **not already covered** by items i, ii, iii, iv, & v to be used in this study?	☐	☒
F	Will **financial inducements** (other than expenses) be offered to participants? If so, please state the amount of financial inducement being offered.	☐	☐
OTHER INFORMATION RELATED TO RISK			
		Yes	**N/A**

King's College London Biomedical & Health Sciences, Dentistry, Medicine and Physical Sciences & Engineering Research Ethics Sub-Committee
BDM/2008/2009/2 1

Figure I.1: Page 1 of the form submitted to the Ethics Committee.



	A human trials questionnaire is needed and has been submitted	☐	☒

4. INVESTIGATORS

4.a Researcher/Principal Investigator Complete ***either*** 'STAFF PROJECTS' **or** 'STUDENT PROJECTS'

STAFF PROJECTS

Researcher's Name: Dr Mark Miodownik

Researcher's Department: Division of Engineering

Researcher's Post: Reader and head of the Materials Research Group

Researcher's Qualifications: PhD

Researcher's relevant experience of research on human participants (If you have ticked **'yes'** to any question in the Risk Checklist summarise here **with reference to those sections ticked 'yes' in Section 3**. Do not submit a cv)**:** None

STUDENT PROJECTS (including PhD)

Student's Name:

Student's Department:

Student's School:

Qualification student is working towards: N/A

Name of Supervisor:

Supervisor's Post:

Supervisor's Qualifications:

Supervisor's Department (if different to student):

Supervisor's relevant experience of research on human participants must be provided (If you have ticked **'yes'** to any question in the Risk Checklist summarise here **with reference to those sections ticked 'yes' in Section 3**. Do not submit a cv)**:**

Supervisor's email address:

4b. Other investigators/collaborators (please note their employer if other than King's College London and ensure that their role and responsibilities within the project are explained here or later in the application)

Martin Conreen; Senior Lecturer in Design, Goldsmith's College, University of London. Conreen will lead on the design and manufacture of the material-objects and on the interpretation of the data gathered.

Harry Witchel; Senior Lecturer in Physiology, Brighton and Sussex Medical School. Witchel will lead on the design of the experiments and on all aspects of the work involving human participants.

Zoe Laughlin; Curator of the Materials Library and Research Assistant in the Materials Research Group, King's College London. Laughlin will assist on all aspects of the project and be the principle experiment supervisor.

5. PREFERRED TIMETABLE

5a. Preferred start date: May 2009 **5b. Projected date of project's completion:** May 2012

6. SPONSOR, OTHER ORGANISATIONS INVOLVED AND FUNDING

SPONSOR Your sponsor will be assumed to be King's College London unless stated otherwise, If King's College London is **not** the sponsor, and therefore **not** responsible for the study, state the name/s of the sponsor below.

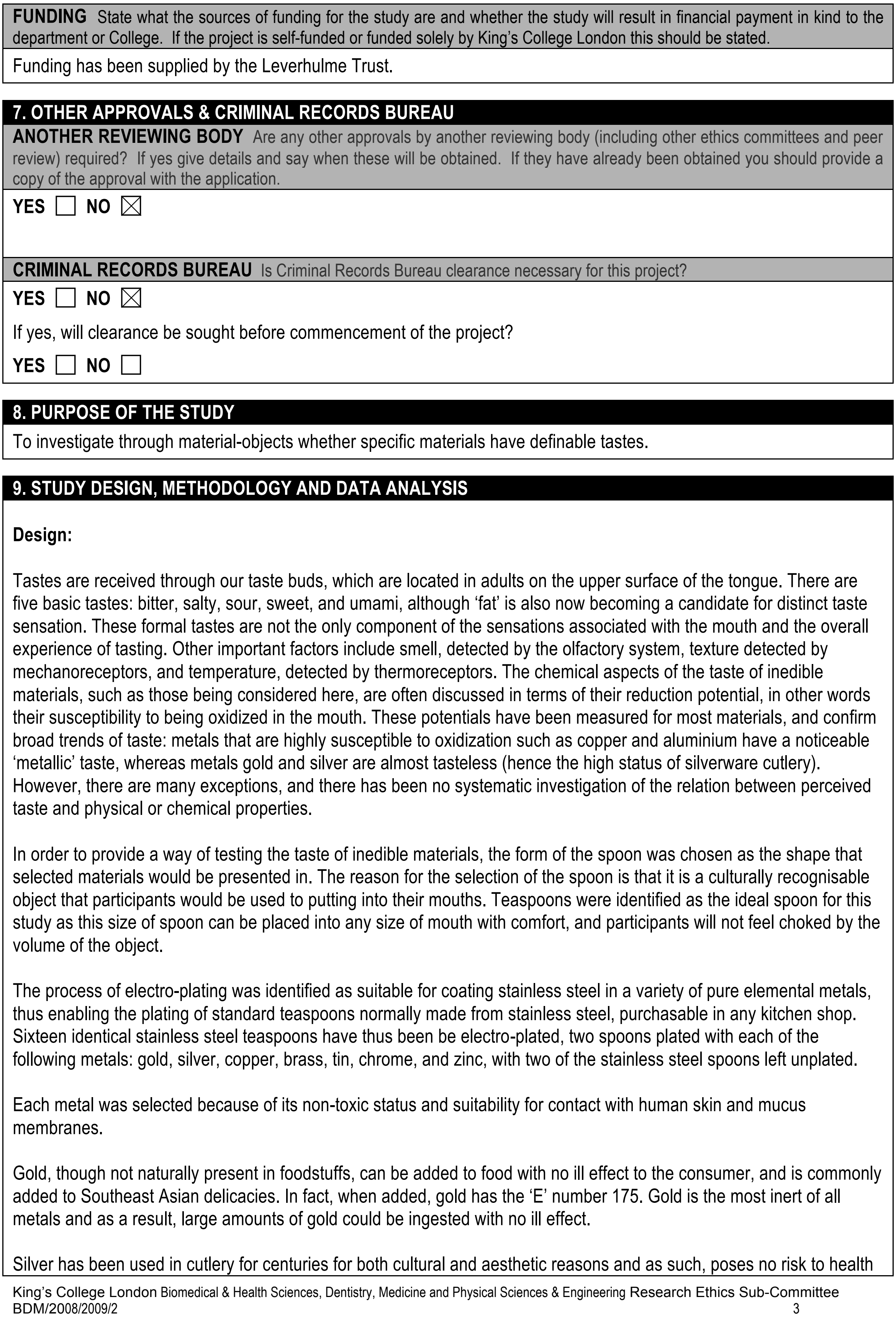
N/A

OTHER ORGANISATIONS Please provide details of any other organisations involved in the project and state their role (e.g. collaborator, gatekeeper). The responsibilities of each organisation should be outlined, you should include any approach letters to gatekeeper organisations and confirm that you will have permission letters available for inspection if requested for audit purposes

Goldsmiths College, University of London and the University of Sussex are involved in the project through the collaborative efforts of Martin Conreen and Harry Witchel.

King's College London Biomedical & Health Sciences, Dentistry, Medicine and Physical Sciences & Engineering Research Ethics Sub-Committee
BDM/2008/2009/2 2

Figure I.2: Page 2 of the form submitted to the Ethics Committee.



FUNDING State what the sources of funding for the study are and whether the study will result in financial payment in kind to the department or College. If the project is self-funded or funded solely by King's College London this should be stated.

Funding has been supplied by the Leverhulme Trust.

7. OTHER APPROVALS & CRIMINAL RECORDS BUREAU

ANOTHER REVIEWING BODY Are any other approvals by another reviewing body (including other ethics committees and peer review) required? If yes give details and say when these will be obtained. If they have already been obtained you should provide a copy of the approval with the application.

YES ☐ **NO** ☒

CRIMINAL RECORDS BUREAU Is Criminal Records Bureau clearance necessary for this project?

YES ☐ **NO** ☒

If yes, will clearance be sought before commencement of the project?

YES ☐ **NO** ☐

8. PURPOSE OF THE STUDY

To investigate through material-objects whether specific materials have definable tastes.

9. STUDY DESIGN, METHODOLOGY AND DATA ANALYSIS

Design:

Tastes are received through our taste buds, which are located in adults on the upper surface of the tongue. There are five basic tastes: bitter, salty, sour, sweet, and umami, although 'fat' is also now becoming a candidate for distinct taste sensation. These formal tastes are not the only component of the sensations associated with the mouth and the overall experience of tasting. Other important factors include smell, detected by the olfactory system, texture detected by mechanoreceptors, and temperature, detected by thermoreceptors. The chemical aspects of the taste of inedible materials, such as those being considered here, are often discussed in terms of their reduction potential, in other words their susceptibility to being oxidized in the mouth. These potentials have been measured for most materials, and confirm broad trends of taste: metals that are highly susceptible to oxidization such as copper and aluminium have a noticeable 'metallic' taste, whereas metals gold and silver are almost tasteless (hence the high status of silverware cutlery). However, there are many exceptions, and there has been no systematic investigation of the relation between perceived taste and physical or chemical properties.

In order to provide a way of testing the taste of inedible materials, the form of the spoon was chosen as the shape that selected materials would be presented in. The reason for the selection of the spoon is that it is a culturally recognisable object that participants would be used to putting into their mouths. Teaspoons were identified as the ideal spoon for this study as this size of spoon can be placed into any size of mouth with comfort, and participants will not feel choked by the volume of the object.

The process of electro-plating was identified as suitable for coating stainless steel in a variety of pure elemental metals, thus enabling the plating of standard teaspoons normally made from stainless steel, purchasable in any kitchen shop. Sixteen identical stainless steel teaspoons have thus been be electro-plated, two spoons plated with each of the following metals: gold, silver, copper, brass, tin, chrome, and zinc, with two of the stainless steel spoons left unplated.

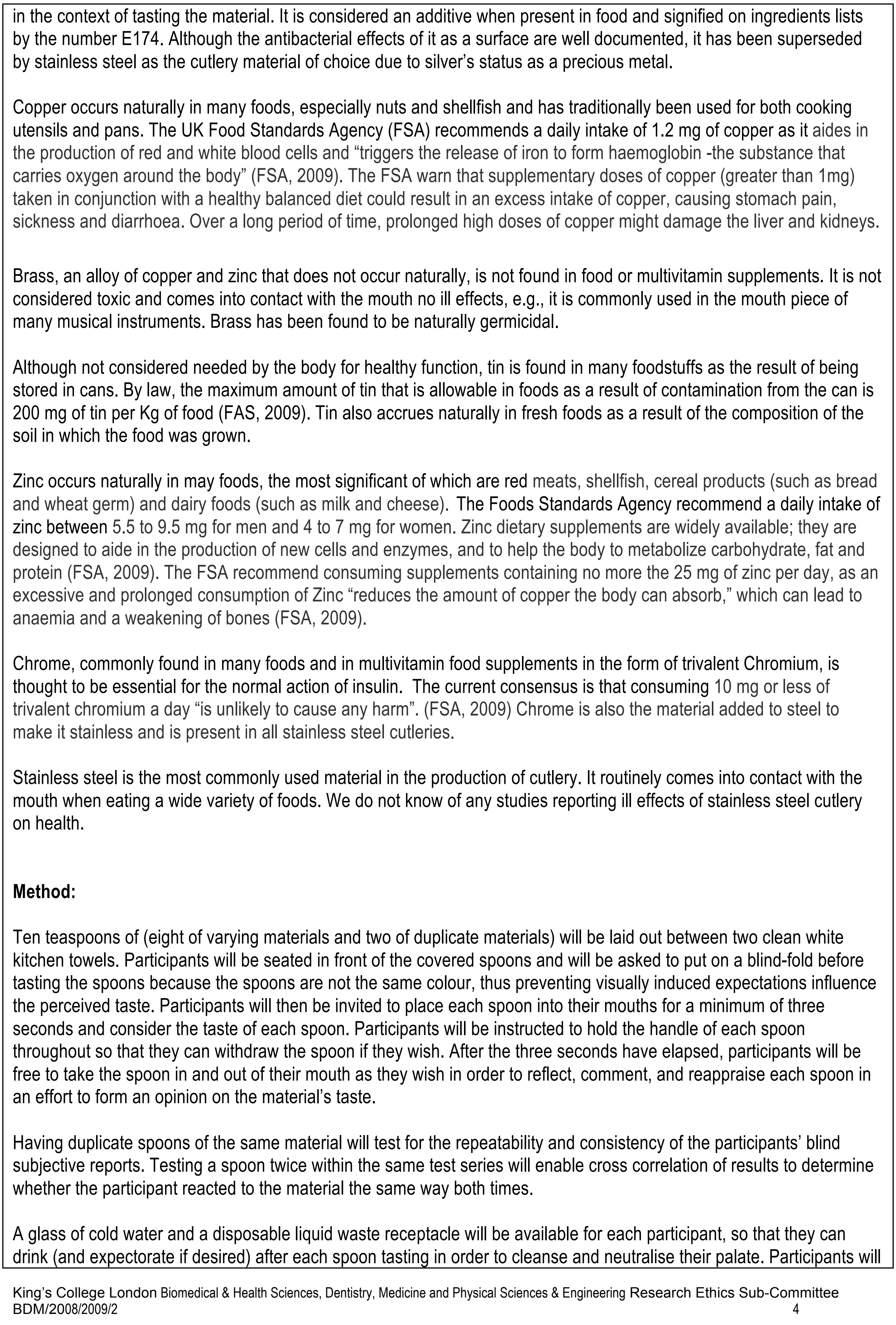
Each metal was selected because of its non-toxic status and suitability for contact with human skin and mucus membranes.

Gold, though not naturally present in foodstuffs, can be added to food with no ill effect to the consumer, and is commonly added to Southeast Asian delicacies. In fact, when added, gold has the 'E' number 175. Gold is the most inert of all metals and as a result, large amounts of gold could be ingested with no ill effect.

Silver has been used in cutlery for centuries for both cultural and aesthetic reasons and as such, poses no risk to health

King's College London Biomedical & Health Sciences, Dentistry, Medicine and Physical Sciences & Engineering Research Ethics Sub-Committee
BDM/2008/2009/2 3

Figure I.3: Page 3 of the form submitted to the Ethics Committee.



in the context of tasting the material. It is considered an additive when present in food and signified on ingredients lists by the number E174. Although the antibacterial effects of it as a surface are well documented, it has been superseded by stainless steel as the cutlery material of choice due to silver's status as a precious metal.

Copper occurs naturally in many foods, especially nuts and shellfish and has traditionally been used for both cooking utensils and pans. The UK Food Standards Agency (FSA) recommends a daily intake of 1.2 mg of copper as it aides in the production of red and white blood cells and "triggers the release of iron to form haemoglobin -the substance that carries oxygen around the body" (FSA, 2009). The FSA warn that supplementary doses of copper (greater than 1mg) taken in conjunction with a healthy balanced diet could result in an excess intake of copper, causing stomach pain, sickness and diarrhoea. Over a long period of time, prolonged high doses of copper might damage the liver and kidneys.

Brass, an alloy of copper and zinc that does not occur naturally, is not found in food or multivitamin supplements. It is not considered toxic and comes into contact with the mouth no ill effects, e.g., it is commonly used in the mouth piece of many musical instruments. Brass has been found to be naturally germicidal.

Although not considered needed by the body for healthy function, tin is found in many foodstuffs as the result of being stored in cans. By law, the maximum amount of tin that is allowable in foods as a result of contamination from the can is 200 mg of tin per Kg of food (FAS, 2009). Tin also accrues naturally in fresh foods as a result of the composition of the soil in which the food was grown.

Zinc occurs naturally in may foods, the most significant of which are red meats, shellfish, cereal products (such as bread and wheat germ) and dairy foods (such as milk and cheese). The Foods Standards Agency recommend a daily intake of zinc between 5.5 to 9.5 mg for men and 4 to 7 mg for women. Zinc dietary supplements are widely available; they are designed to aide in the production of new cells and enzymes, and to help the body to metabolize carbohydrate, fat and protein (FSA, 2009). The FSA recommend consuming supplements containing no more the 25 mg of zinc per day, as an excessive and prolonged consumption of Zinc "reduces the amount of copper the body can absorb," which can lead to anaemia and a weakening of bones (FSA, 2009).

Chrome, commonly found in many foods and in multivitamin food supplements in the form of trivalent Chromium, is thought to be essential for the normal action of insulin. The current consensus is that consuming 10 mg or less of trivalent chromium a day "is unlikely to cause any harm". (FSA, 2009) Chrome is also the material added to steel to make it stainless and is present in all stainless steel cutleries.

Stainless steel is the most commonly used material in the production of cutlery. It routinely comes into contact with the mouth when eating a wide variety of foods. We do not know of any studies reporting ill effects of stainless steel cutlery on health.

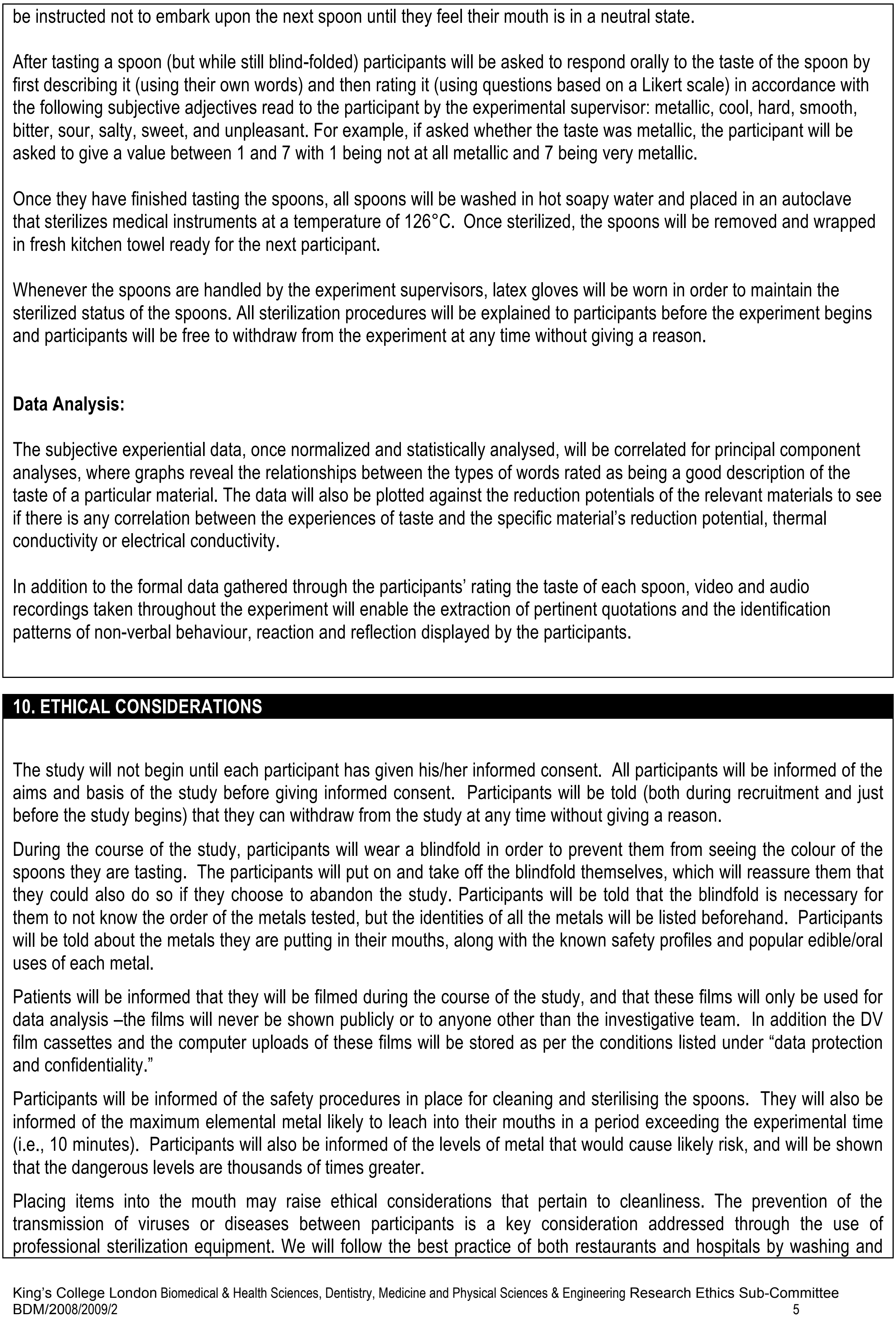
Method:

Ten teaspoons of (eight of varying materials and two of duplicate materials) will be laid out between two clean white kitchen towels. Participants will be seated in front of the covered spoons and will be asked to put on a blind-fold before tasting the spoons because the spoons are not the same colour, thus preventing visually induced expectations influence the perceived taste. Participants will then be invited to place each spoon into their mouths for a minimum of three seconds and consider the taste of each spoon. Participants will be instructed to hold the handle of each spoon throughout so that they can withdraw the spoon if they wish. After the three seconds have elapsed, participants will be free to take the spoon in and out of their mouth as they wish in order to reflect, comment, and reappraise each spoon in an effort to form an opinion on the material's taste.

Having duplicate spoons of the same material will test for the repeatability and consistency of the participants' blind subjective reports. Testing a spoon twice within the same test series will enable cross correlation of results to determine whether the participant reacted to the material the same way both times.

A glass of cold water and a disposable liquid waste receptacle will be available for each participant, so that they can drink (and expectorate if desired) after each spoon tasting in order to cleanse and neutralise their palate. Participants will

Figure I.4: Page 4 of the form submitted to the Ethics Committee.



be instructed not to embark upon the next spoon until they feel their mouth is in a neutral state.

After tasting a spoon (but while still blind-folded) participants will be asked to respond orally to the taste of the spoon by first describing it (using their own words) and then rating it (using questions based on a Likert scale) in accordance with the following subjective adjectives read to the participant by the experimental supervisor: metallic, cool, hard, smooth, bitter, sour, salty, sweet, and unpleasant. For example, if asked whether the taste was metallic, the participant will be asked to give a value between 1 and 7 with 1 being not at all metallic and 7 being very metallic.

Once they have finished tasting the spoons, all spoons will be washed in hot soapy water and placed in an autoclave that sterilizes medical instruments at a temperature of 126°C. Once sterilized, the spoons will be removed and wrapped in fresh kitchen towel ready for the next participant.

Whenever the spoons are handled by the experiment supervisors, latex gloves will be worn in order to maintain the sterilized status of the spoons. All sterilization procedures will be explained to participants before the experiment begins and participants will be free to withdraw from the experiment at any time without giving a reason.

Data Analysis:

The subjective experiential data, once normalized and statistically analysed, will be correlated for principal component analyses, where graphs reveal the relationships between the types of words rated as being a good description of the taste of a particular material. The data will also be plotted against the reduction potentials of the relevant materials to see if there is any correlation between the experiences of taste and the specific material's reduction potential, thermal conductivity or electrical conductivity.

In addition to the formal data gathered through the participants' rating the taste of each spoon, video and audio recordings taken throughout the experiment will enable the extraction of pertinent quotations and the identification patterns of non-verbal behaviour, reaction and reflection displayed by the participants.

10. ETHICAL CONSIDERATIONS

The study will not begin until each participant has given his/her informed consent. All participants will be informed of the aims and basis of the study before giving informed consent. Participants will be told (both during recruitment and just before the study begins) that they can withdraw from the study at any time without giving a reason.

During the course of the study, participants will wear a blindfold in order to prevent them from seeing the colour of the spoons they are tasting. The participants will put on and take off the blindfold themselves, which will reassure them that they could also do so if they choose to abandon the study. Participants will be told that the blindfold is necessary for them to not know the order of the metals tested, but the identities of all the metals will be listed beforehand. Participants will be told about the metals they are putting in their mouths, along with the known safety profiles and popular edible/oral uses of each metal.

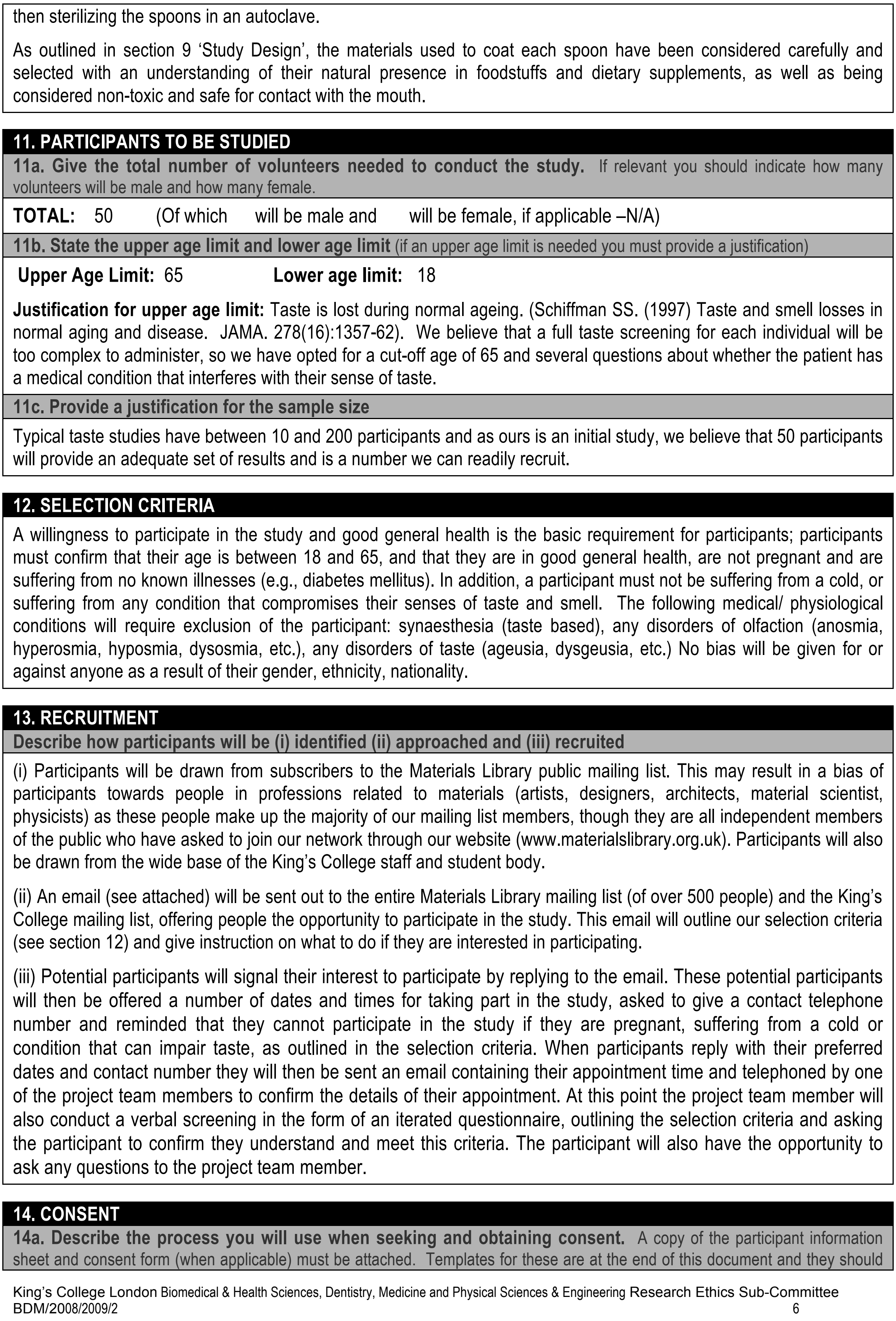
Patients will be informed that they will be filmed during the course of the study, and that these films will only be used for data analysis –the films will never be shown publicly or to anyone other than the investigative team. In addition the DV film cassettes and the computer uploads of these films will be stored as per the conditions listed under "data protection and confidentiality."

Participants will be informed of the safety procedures in place for cleaning and sterilising the spoons. They will also be informed of the maximum elemental metal likely to leach into their mouths in a period exceeding the experimental time (i.e., 10 minutes). Participants will also be informed of the levels of metal that would cause likely risk, and will be shown that the dangerous levels are thousands of times greater.

Placing items into the mouth may raise ethical considerations that pertain to cleanliness. The prevention of the transmission of viruses or diseases between participants is a key consideration addressed through the use of professional sterilization equipment. We will follow the best practice of both restaurants and hospitals by washing and

King's College London Biomedical & Health Sciences, Dentistry, Medicine and Physical Sciences & Engineering Research Ethics Sub-Committee
BDM/2008/2009/2 5

Figure I.5: Page 5 of the form submitted to the Ethics Committee.



then sterilizing the spoons in an autoclave.

As outlined in section 9 'Study Design', the materials used to coat each spoon have been considered carefully and selected with an understanding of their natural presence in foodstuffs and dietary supplements, as well as being considered non-toxic and safe for contact with the mouth.

11. PARTICIPANTS TO BE STUDIED

11a. Give the total number of volunteers needed to conduct the study. If relevant you should indicate how many volunteers will be male and how many female.

TOTAL: 50 (Of which will be male and will be female, if applicable –N/A)

11b. State the upper age limit and lower age limit (if an upper age limit is needed you must provide a justification)

Upper Age Limit: 65 **Lower age limit:** 18

Justification for upper age limit: Taste is lost during normal ageing. (Schiffman SS. (1997) Taste and smell losses in normal aging and disease. JAMA. 278(16):1357-62). We believe that a full taste screening for each individual will be too complex to administer, so we have opted for a cut-off age of 65 and several questions about whether the patient has a medical condition that interferes with their sense of taste.

11c. Provide a justification for the sample size

Typical taste studies have between 10 and 200 participants and as ours is an initial study, we believe that 50 participants will provide an adequate set of results and is a number we can readily recruit.

12. SELECTION CRITERIA

A willingness to participate in the study and good general health is the basic requirement for participants; participants must confirm that their age is between 18 and 65, and that they are in good general health, are not pregnant and are suffering from no known illnesses (e.g., diabetes mellitus). In addition, a participant must not be suffering from a cold, or suffering from any condition that compromises their senses of taste and smell. The following medical/ physiological conditions will require exclusion of the participant: synaesthesia (taste based), any disorders of olfaction (anosmia, hyperosmia, hyposmia, dysosmia, etc.), any disorders of taste (ageusia, dysgeusia, etc.) No bias will be given for or against anyone as a result of their gender, ethnicity, nationality.

13. RECRUITMENT

Describe how participants will be (i) identified (ii) approached and (iii) recruited

(i) Participants will be drawn from subscribers to the Materials Library public mailing list. This may result in a bias of participants towards people in professions related to materials (artists, designers, architects, material scientist, physicists) as these people make up the majority of our mailing list members, though they are all independent members of the public who have asked to join our network through our website (www.materialslibrary.org.uk). Participants will also be drawn from the wide base of the King's College staff and student body.

(ii) An email (see attached) will be sent out to the entire Materials Library mailing list (of over 500 people) and the King's College mailing list, offering people the opportunity to participate in the study. This email will outline our selection criteria (see section 12) and give instruction on what to do if they are interested in participating.

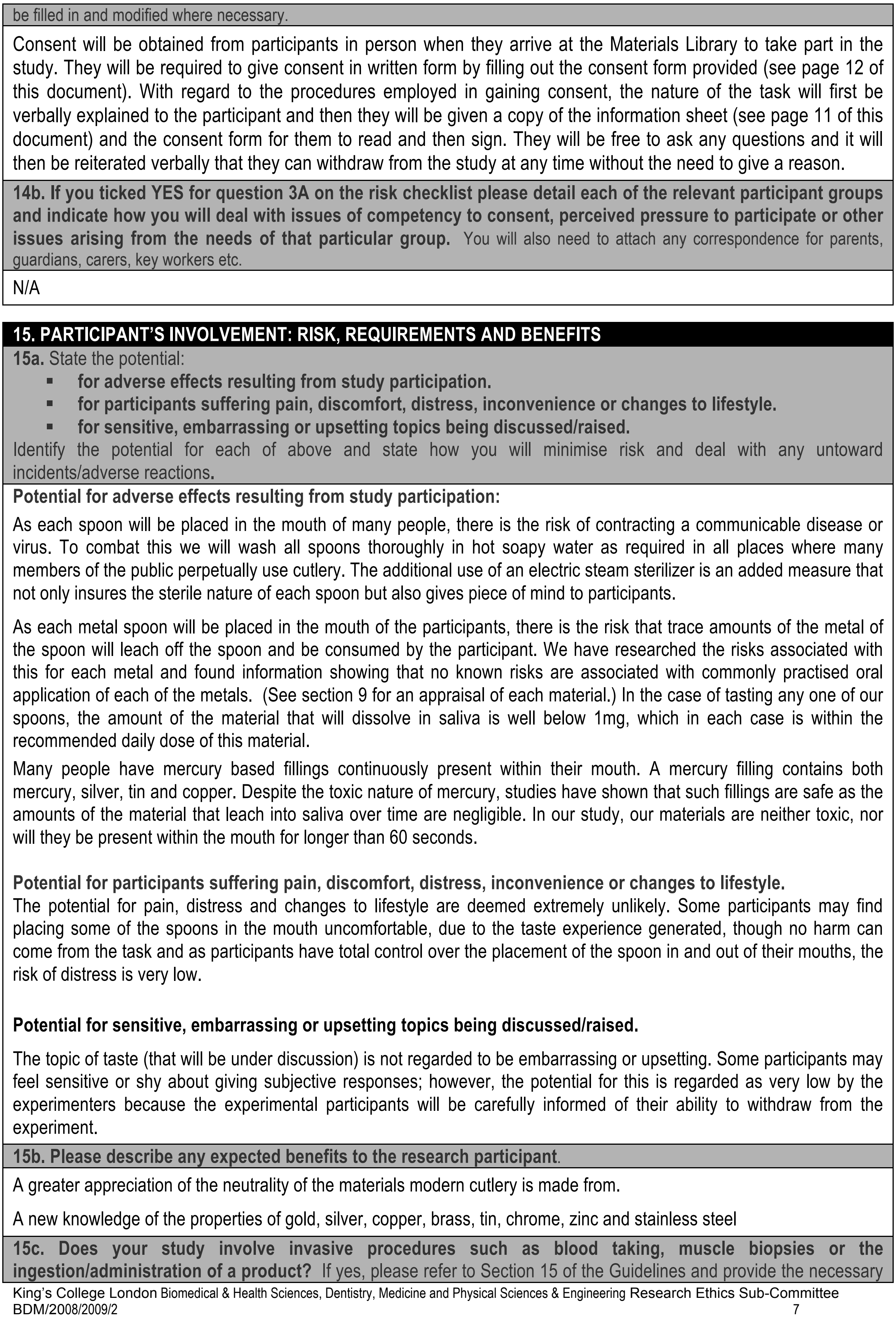
(iii) Potential participants will signal their interest to participate by replying to the email. These potential participants will then be offered a number of dates and times for taking part in the study, asked to give a contact telephone number and reminded that they cannot participate in the study if they are pregnant, suffering from a cold or condition that can impair taste, as outlined in the selection criteria. When participants reply with their preferred dates and contact number they will then be sent an email containing their appointment time and telephoned by one of the project team members to confirm the details of their appointment. At this point the project team member will also conduct a verbal screening in the form of an iterated questionnaire, outlining the selection criteria and asking the participant to confirm they understand and meet this criteria. The participant will also have the opportunity to ask any questions to the project team member.

14. CONSENT

14a. Describe the process you will use when seeking and obtaining consent. A copy of the participant information sheet and consent form (when applicable) must be attached. Templates for these are at the end of this document and they should

King's College London Biomedical & Health Sciences, Dentistry, Medicine and Physical Sciences & Engineering Research Ethics Sub-Committee
BDM/2008/2009/2 6

Figure I.6: Page 6 of the form submitted to the Ethics Committee.



be filled in and modified where necessary.

Consent will be obtained from participants in person when they arrive at the Materials Library to take part in the study. They will be required to give consent in written form by filling out the consent form provided (see page 12 of this document). With regard to the procedures employed in gaining consent, the nature of the task will first be verbally explained to the participant and then they will be given a copy of the information sheet (see page 11 of this document) and the consent form for them to read and then sign. They will be free to ask any questions and it will then be reiterated verbally that they can withdraw from the study at any time without the need to give a reason.

14b. If you ticked YES for question 3A on the risk checklist please detail each of the relevant participant groups and indicate how you will deal with issues of competency to consent, perceived pressure to participate or other issues arising from the needs of that particular group. You will also need to attach any correspondence for parents, guardians, carers, key workers etc.

N/A

15. PARTICIPANT'S INVOLVEMENT: RISK, REQUIREMENTS AND BENEFITS

15a. State the potential:

- **for adverse effects resulting from study participation.**
- **for participants suffering pain, discomfort, distress, inconvenience or changes to lifestyle.**
- **for sensitive, embarrassing or upsetting topics being discussed/raised.**

Identify the potential for each of above and state how you will minimise risk and deal with any untoward incidents/adverse reactions.

Potential for adverse effects resulting from study participation:

As each spoon will be placed in the mouth of many people, there is the risk of contracting a communicable disease or virus. To combat this we will wash all spoons thoroughly in hot soapy water as required in all places where many members of the public perpetually use cutlery. The additional use of an electric steam sterilizer is an added measure that not only insures the sterile nature of each spoon but also gives piece of mind to participants.

As each metal spoon will be placed in the mouth of the participants, there is the risk that trace amounts of the metal of the spoon will leach off the spoon and be consumed by the participant. We have researched the risks associated with this for each metal and found information showing that no known risks are associated with commonly practised oral application of each of the metals. (See section 9 for an appraisal of each material.) In the case of tasting any one of our spoons, the amount of the material that will dissolve in saliva is well below 1mg, which in each case is within the recommended daily dose of this material.

Many people have mercury based fillings continuously present within their mouth. A mercury filling contains both mercury, silver, tin and copper. Despite the toxic nature of mercury, studies have shown that such fillings are safe as the amounts of the material that leach into saliva over time are negligible. In our study, our materials are neither toxic, nor will they be present within the mouth for longer than 60 seconds.

Potential for participants suffering pain, discomfort, distress, inconvenience or changes to lifestyle.

The potential for pain, distress and changes to lifestyle are deemed extremely unlikely. Some participants may find placing some of the spoons in the mouth uncomfortable, due to the taste experience generated, though no harm can come from the task and as participants have total control over the placement of the spoon in and out of their mouths, the risk of distress is very low.

Potential for sensitive, embarrassing or upsetting topics being discussed/raised.

The topic of taste (that will be under discussion) is not regarded to be embarrassing or upsetting. Some participants may feel sensitive or shy about giving subjective responses; however, the potential for this is regarded as very low by the experimenters because the experimental participants will be carefully informed of their ability to withdraw from the experiment.

15b. Please describe any expected benefits to the research participant.

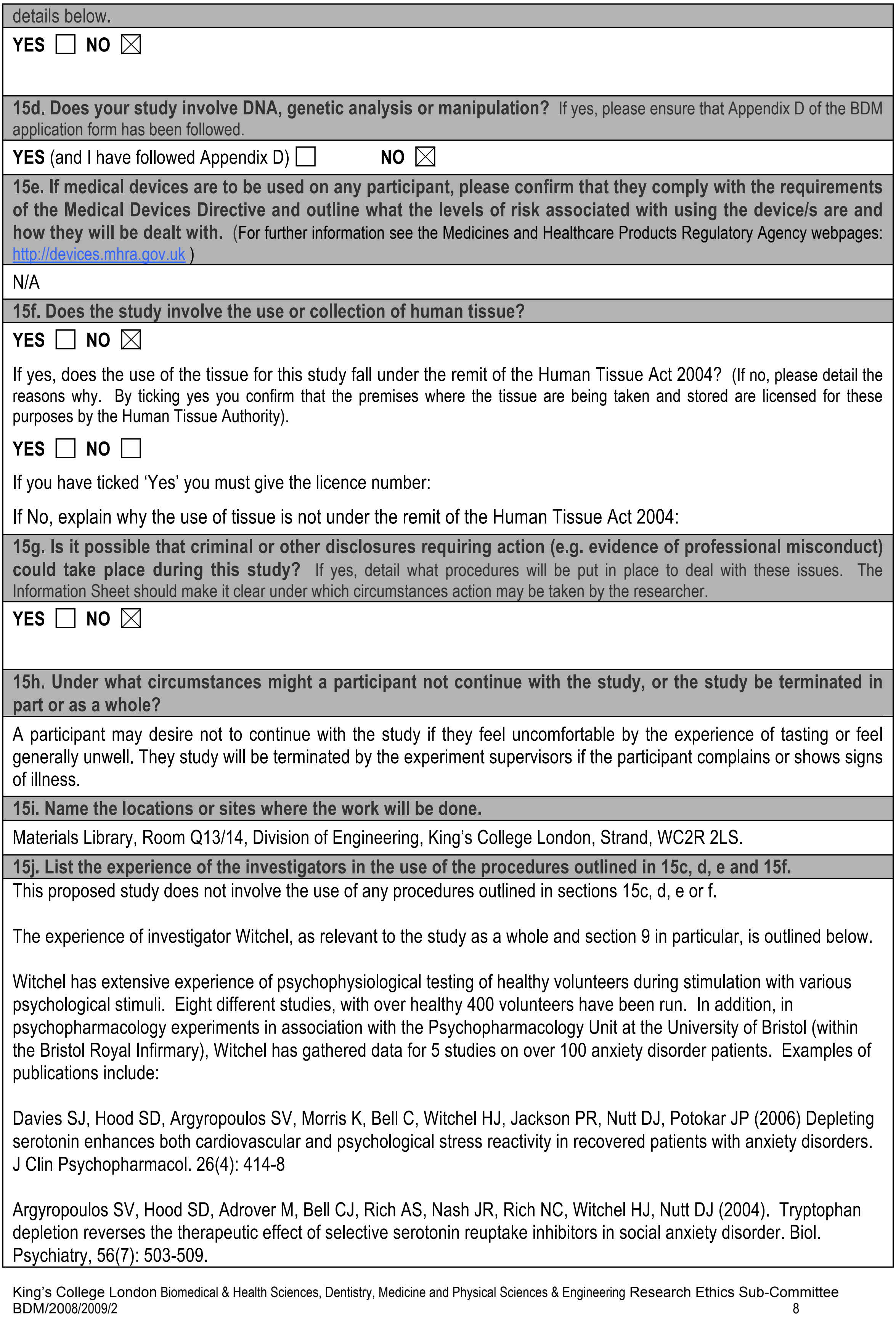
A greater appreciation of the neutrality of the materials modern cutlery is made from.

A new knowledge of the properties of gold, silver, copper, brass, tin, chrome, zinc and stainless steel

15c. Does your study involve invasive procedures such as blood taking, muscle biopsies or the ingestion/administration of a product? If yes, please refer to Section 15 of the Guidelines and provide the necessary

King's College London Biomedical & Health Sciences, Dentistry, Medicine and Physical Sciences & Engineering Research Ethics Sub-Committee
BDM/2008/2009/2 7

Figure I.7: Page 7 of the form submitted to the Ethics Committee.



details below.

YES ☐ **NO** ☒

15d. Does your study involve DNA, genetic analysis or manipulation? If yes, please ensure that Appendix D of the BDM application form has been followed.

YES (and I have followed Appendix D) ☐ **NO** ☒

15e. If medical devices are to be used on any participant, please confirm that they comply with the requirements of the Medical Devices Directive and outline what the levels of risk associated with using the device/s are and how they will be dealt with. (For further information see the Medicines and Healthcare Products Regulatory Agency webpages: http://devices.mhra.gov.uk)

N/A

15f. Does the study involve the use or collection of human tissue?

YES ☐ **NO** ☒

If yes, does the use of the tissue for this study fall under the remit of the Human Tissue Act 2004? (If no, please detail the reasons why. By ticking yes you confirm that the premises where the tissue are being taken and stored are licensed for these purposes by the Human Tissue Authority).

YES ☐ **NO** ☐

If you have ticked 'Yes' you must give the licence number:

If No, explain why the use of tissue is not under the remit of the Human Tissue Act 2004:

15g. Is it possible that criminal or other disclosures requiring action (e.g. evidence of professional misconduct) could take place during this study? If yes, detail what procedures will be put in place to deal with these issues. The Information Sheet should make it clear under which circumstances action may be taken by the researcher.

YES ☐ **NO** ☒

15h. Under what circumstances might a participant not continue with the study, or the study be terminated in part or as a whole?

A participant may desire not to continue with the study if they feel uncomfortable by the experience of tasting or feel generally unwell. They study will be terminated by the experiment supervisors if the participant complains or shows signs of illness.

15i. Name the locations or sites where the work will be done.

Materials Library, Room Q13/14, Division of Engineering, King's College London, Strand, WC2R 2LS.

15j. List the experience of the investigators in the use of the procedures outlined in 15c, d, e and 15f.

This proposed study does not involve the use of any procedures outlined in sections 15c, d, e or f.

The experience of investigator Witchel, as relevant to the study as a whole and section 9 in particular, is outlined below.

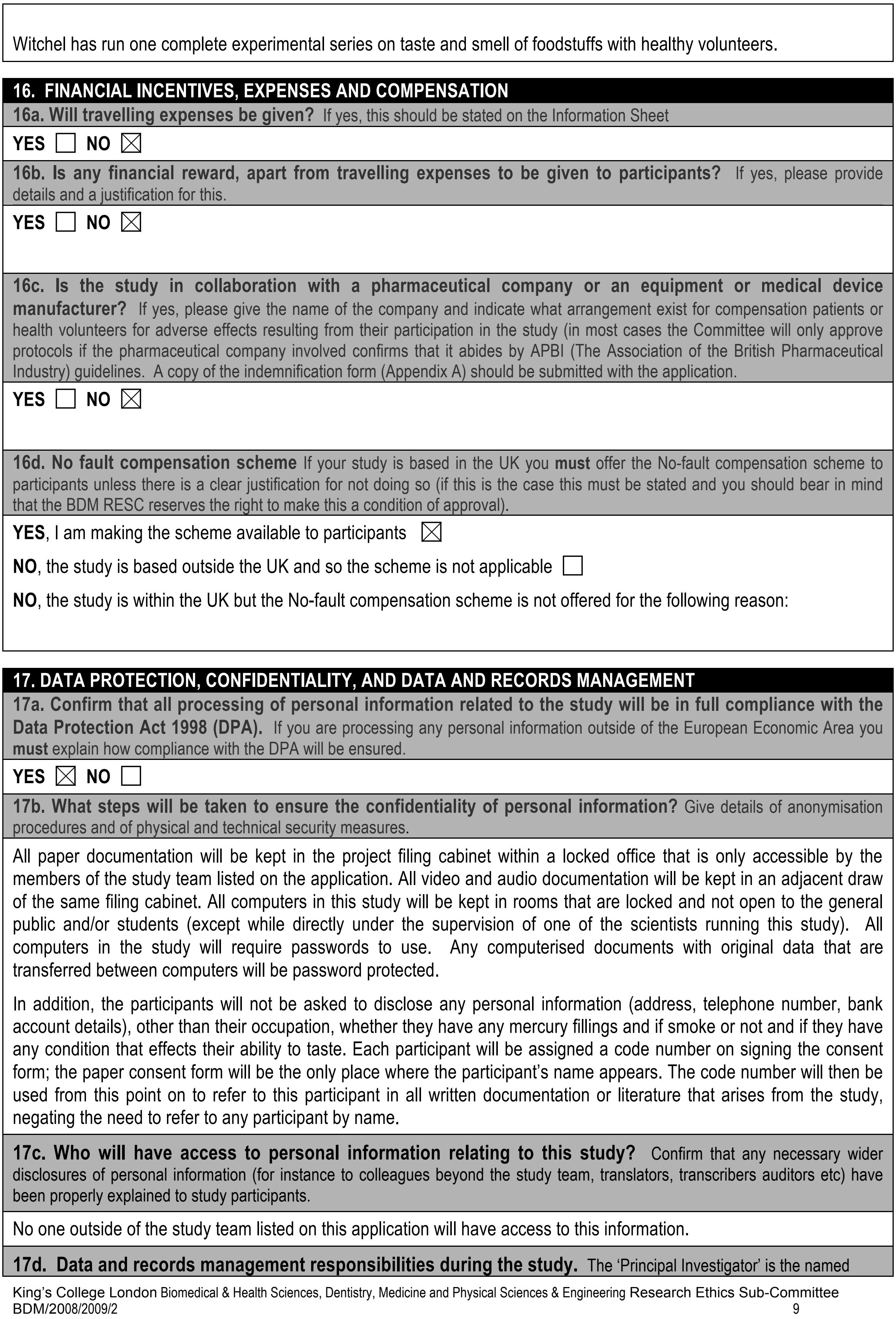
Witchel has extensive experience of psychophysiological testing of healthy volunteers during stimulation with various psychological stimuli. Eight different studies, with over healthy 400 volunteers have been run. In addition, in psychopharmacology experiments in association with the Psychopharmacology Unit at the University of Bristol (within the Bristol Royal Infirmary), Witchel has gathered data for 5 studies on over 100 anxiety disorder patients. Examples of publications include:

Davies SJ, Hood SD, Argyropoulos SV, Morris K, Bell C, Witchel HJ, Jackson PR, Nutt DJ, Potokar JP (2006) Depleting serotonin enhances both cardiovascular and psychological stress reactivity in recovered patients with anxiety disorders. J Clin Psychopharmacol. 26(4): 414-8

Argyropoulos SV, Hood SD, Adrover M, Bell CJ, Rich AS, Nash JR, Rich NC, Witchel HJ, Nutt DJ (2004). Tryptophan depletion reverses the therapeutic effect of selective serotonin reuptake inhibitors in social anxiety disorder. Biol. Psychiatry, 56(7): 503-509.

King's College London Biomedical & Health Sciences, Dentistry, Medicine and Physical Sciences & Engineering Research Ethics Sub-Committee
BDM/2008/2009/2 8

Figure I.8: Page 8 of the form submitted to the Ethics Committee.



Witchel has run one complete experimental series on taste and smell of foodstuffs with healthy volunteers.

16. FINANCIAL INCENTIVES, EXPENSES AND COMPENSATION

16a. Will travelling expenses be given? If yes, this should be stated on the Information Sheet

YES ☐ **NO** ☒

16b. Is any financial reward, apart from travelling expenses to be given to participants? If yes, please provide details and a justification for this.

YES ☐ **NO** ☒

16c. Is the study in collaboration with a pharmaceutical company or an equipment or medical device manufacturer? If yes, please give the name of the company and indicate what arrangement exist for compensation patients or health volunteers for adverse effects resulting from their participation in the study (in most cases the Committee will only approve protocols if the pharmaceutical company involved confirms that it abides by APBI (The Association of the British Pharmaceutical Industry) guidelines. A copy of the indemnification form (Appendix A) should be submitted with the application.

YES ☐ **NO** ☒

16d. No fault compensation scheme If your study is based in the UK you **must** offer the No-fault compensation scheme to participants unless there is a clear justification for not doing so (if this is the case this must be stated and you should bear in mind that the BDM RESC reserves the right to make this a condition of approval).

YES, I am making the scheme available to participants ☒

NO, the study is based outside the UK and so the scheme is not applicable ☐

NO, the study is within the UK but the No-fault compensation scheme is not offered for the following reason:

17. DATA PROTECTION, CONFIDENTIALITY, AND DATA AND RECORDS MANAGEMENT

17a. Confirm that all processing of personal information related to the study will be in full compliance with the Data Protection Act 1998 (DPA). If you are processing any personal information outside of the European Economic Area you **must** explain how compliance with the DPA will be ensured.

YES ☒ **NO** ☐

17b. What steps will be taken to ensure the confidentiality of personal information? Give details of anonymisation procedures and of physical and technical security measures.

All paper documentation will be kept in the project filing cabinet within a locked office that is only accessible by the members of the study team listed on the application. All video and audio documentation will be kept in an adjacent draw of the same filing cabinet. All computers in this study will be kept in rooms that are locked and not open to the general public and/or students (except while directly under the supervision of one of the scientists running this study). All computers in the study will require passwords to use. Any computerised documents with original data that are transferred between computers will be password protected.

In addition, the participants will not be asked to disclose any personal information (address, telephone number, bank account details), other than their occupation, whether they have any mercury fillings and if smoke or not and if they have any condition that effects their ability to taste. Each participant will be assigned a code number on signing the consent form; the paper consent form will be the only place where the participant's name appears. The code number will then be used from this point on to refer to this participant in all written documentation or literature that arises from the study, negating the need to refer to any participant by name.

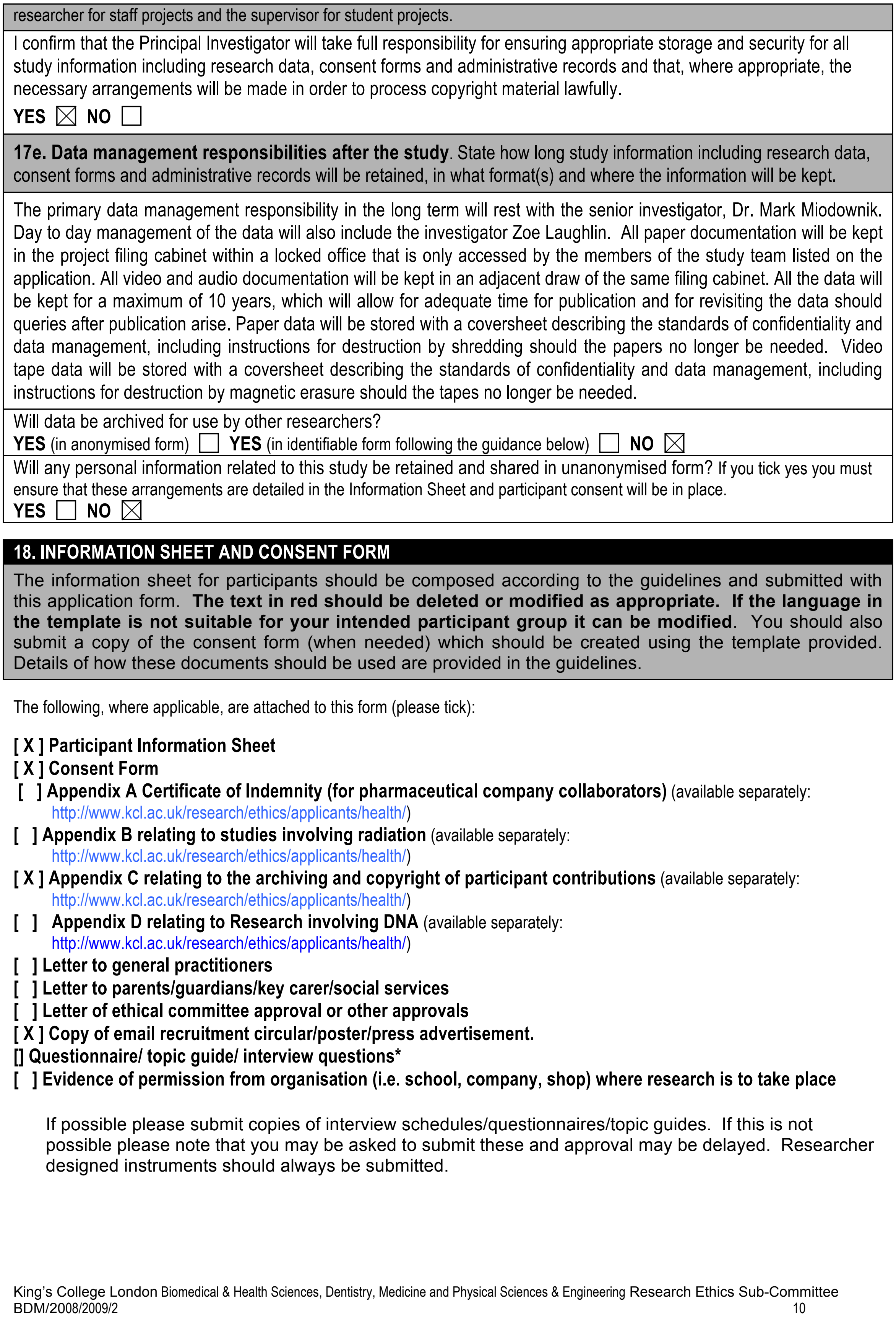
17c. Who will have access to personal information relating to this study? Confirm that any necessary wider disclosures of personal information (for instance to colleagues beyond the study team, translators, transcribers auditors etc) have been properly explained to study participants.

No one outside of the study team listed on this application will have access to this information.

17d. Data and records management responsibilities during the study. The 'Principal Investigator' is the named

King's College London Biomedical & Health Sciences, Dentistry, Medicine and Physical Sciences & Engineering Research Ethics Sub-Committee
BDM/2008/2009/2 9

Figure I.9: Page 9 of the form submitted to the Ethics Committee.



researcher for staff projects and the supervisor for student projects.

I confirm that the Principal Investigator will take full responsibility for ensuring appropriate storage and security for all study information including research data, consent forms and administrative records and that, where appropriate, the necessary arrangements will be made in order to process copyright material lawfully.

YES ☒ **NO** ☐

17e. Data management responsibilities after the study. State how long study information including research data, consent forms and administrative records will be retained, in what format(s) and where the information will be kept.

The primary data management responsibility in the long term will rest with the senior investigator, Dr. Mark Miodownik. Day to day management of the data will also include the investigator Zoe Laughlin. All paper documentation will be kept in the project filing cabinet within a locked office that is only accessed by the members of the study team listed on the application. All video and audio documentation will be kept in an adjacent draw of the same filing cabinet. All the data will be kept for a maximum of 10 years, which will allow for adequate time for publication and for revisiting the data should queries after publication arise. Paper data will be stored with a coversheet describing the standards of confidentiality and data management, including instructions for destruction by shredding should the papers no longer be needed. Video tape data will be stored with a coversheet describing the standards of confidentiality and data management, including instructions for destruction by magnetic erasure should the tapes no longer be needed.

Will data be archived for use by other researchers?
YES (in anonymised form) ☐ **YES** (in identifiable form following the guidance below) ☐ **NO** ☒

Will any personal information related to this study be retained and shared in unanonymised form? If you tick yes you must ensure that these arrangements are detailed in the Information Sheet and participant consent will be in place.
YES ☐ **NO** ☒

18. INFORMATION SHEET AND CONSENT FORM

The information sheet for participants should be composed according to the guidelines and submitted with this application form. **The text in red should be deleted or modified as appropriate. If the language in the template is not suitable for your intended participant group it can be modified**. You should also submit a copy of the consent form (when needed) which should be created using the template provided. Details of how these documents should be used are provided in the guidelines.

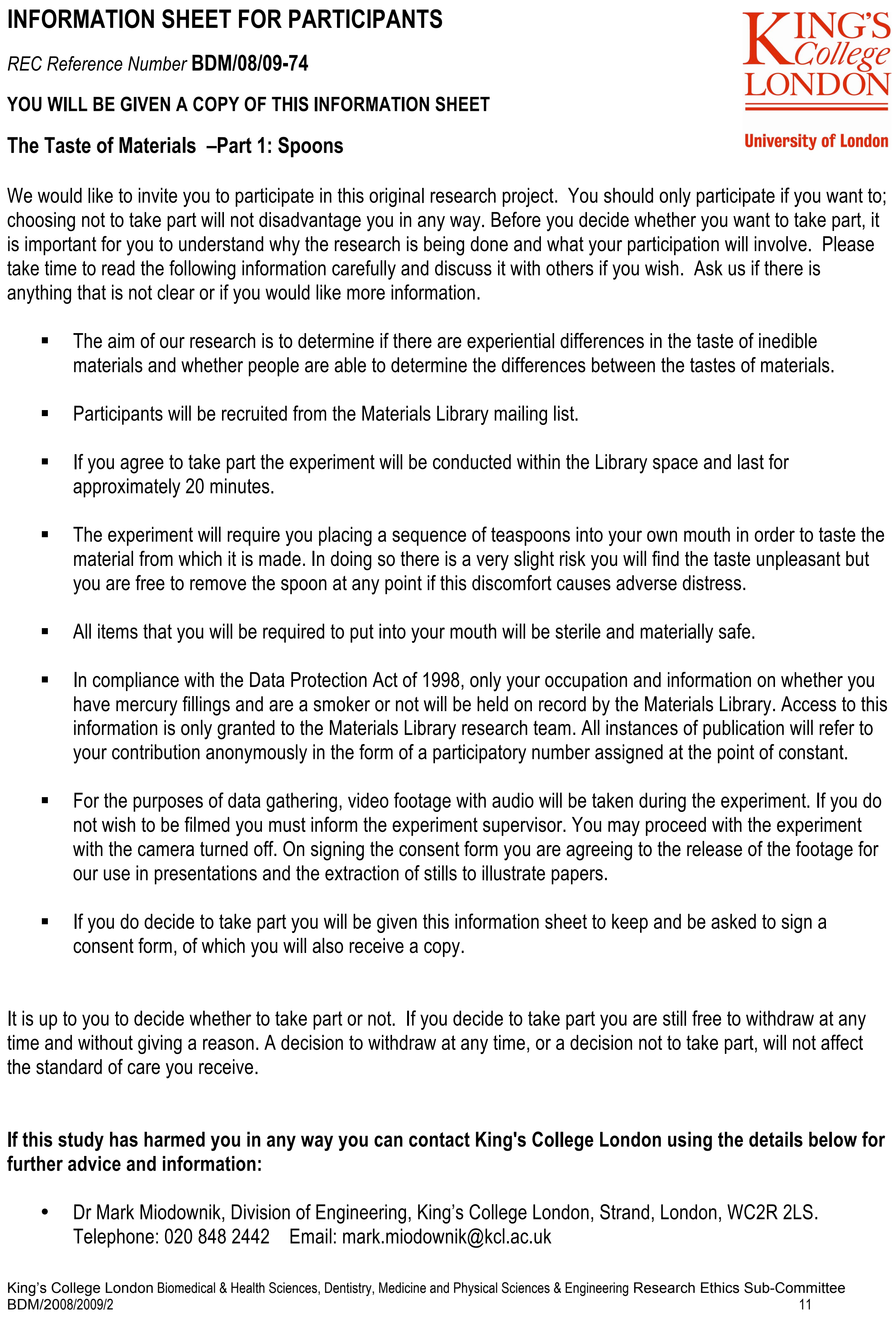
The following, where applicable, are attached to this form (please tick):

[X] Participant Information Sheet
[X] Consent Form
[ ] Appendix A Certificate of Indemnity (for pharmaceutical company collaborators) (available separately:
http://www.kcl.ac.uk/research/ethics/applicants/health/)
[ ] Appendix B relating to studies involving radiation (available separately:
http://www.kcl.ac.uk/research/ethics/applicants/health/)
[X] Appendix C relating to the archiving and copyright of participant contributions (available separately:
http://www.kcl.ac.uk/research/ethics/applicants/health/)
[ ] Appendix D relating to Research involving DNA (available separately:
http://www.kcl.ac.uk/research/ethics/applicants/health/)
[ ] Letter to general practitioners
[ ] Letter to parents/guardians/key carer/social services
[ ] Letter of ethical committee approval or other approvals
[X] Copy of email recruitment circular/poster/press advertisement.
[] Questionnaire/ topic guide/ interview questions*
[ ] Evidence of permission from organisation (i.e. school, company, shop) where research is to take place

If possible please submit copies of interview schedules/questionnaires/topic guides. If this is not possible please note that you may be asked to submit these and approval may be delayed. Researcher designed instruments should always be submitted.

King's College London Biomedical & Health Sciences, Dentistry, Medicine and Physical Sciences & Engineering Research Ethics Sub-Committee
BDM/2008/2009/2 10

Figure I.10: Page 10 of the form submitted to the Ethics Committee.



INFORMATION SHEET FOR PARTICIPANTS

KING'S College LONDON
University of London

REC Reference Number **BDM/08/09-74**

YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET

The Taste of Materials –Part 1: Spoons

We would like to invite you to participate in this original research project. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

- The aim of our research is to determine if there are experiential differences in the taste of inedible materials and whether people are able to determine the differences between the tastes of materials.
- Participants will be recruited from the Materials Library mailing list.
- If you agree to take part the experiment will be conducted within the Library space and last for approximately 20 minutes.
- The experiment will require you placing a sequence of teaspoons into your own mouth in order to taste the material from which it is made. In doing so there is a very slight risk you will find the taste unpleasant but you are free to remove the spoon at any point if this discomfort causes adverse distress.
- All items that you will be required to put into your mouth will be sterile and materially safe.
- In compliance with the Data Protection Act of 1998, only your occupation and information on whether you have mercury fillings and are a smoker or not will be held on record by the Materials Library. Access to this information is only granted to the Materials Library research team. All instances of publication will refer to your contribution anonymously in the form of a participatory number assigned at the point of constant.
- For the purposes of data gathering, video footage with audio will be taken during the experiment. If you do not wish to be filmed you must inform the experiment supervisor. You may proceed with the experiment with the camera turned off. On signing the consent form you are agreeing to the release of the footage for our use in presentations and the extraction of stills to illustrate papers.
- If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form, of which you will also receive a copy.

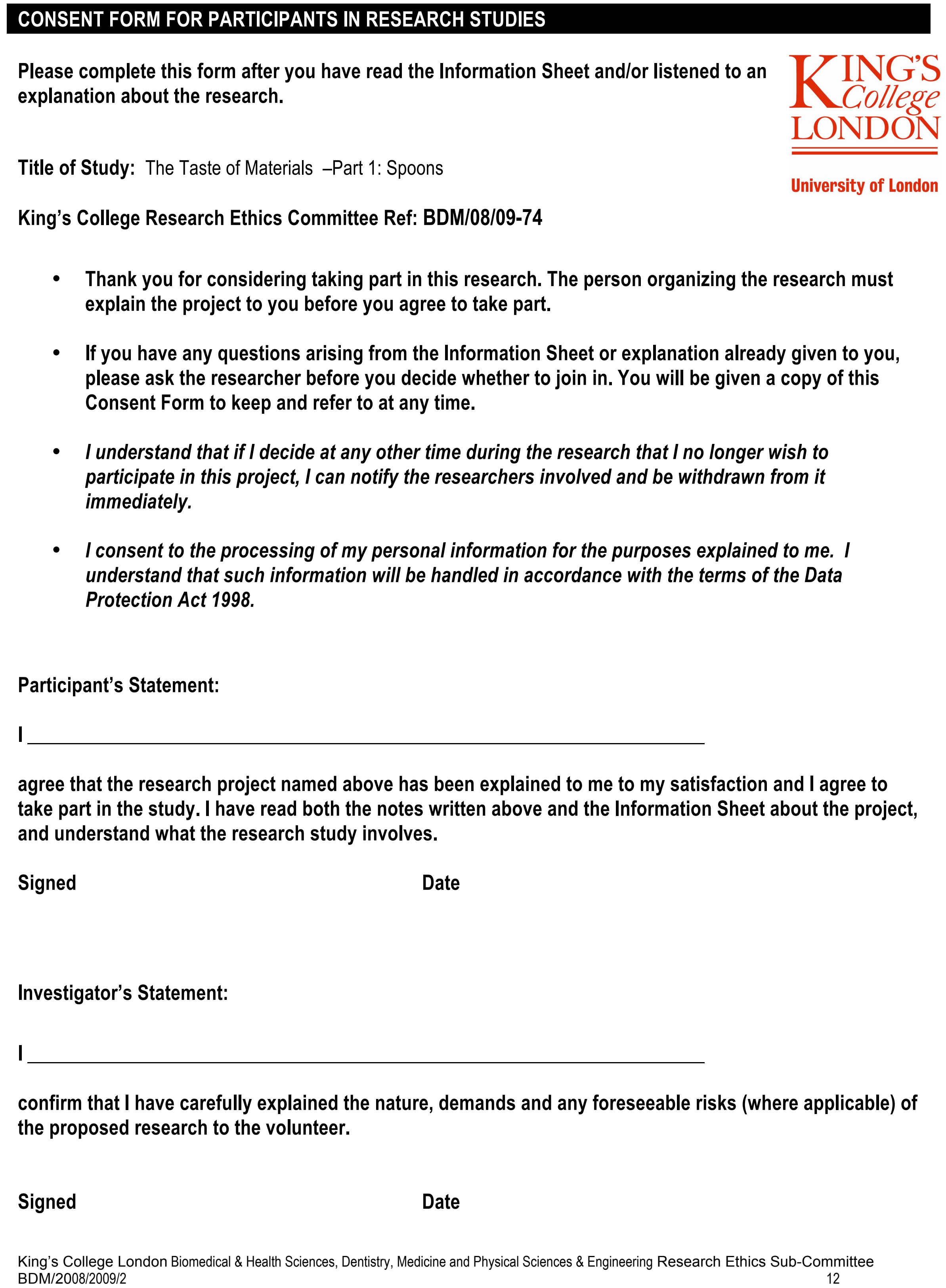
It is up to you to decide whether to take part or not. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care you receive.

If this study has harmed you in any way you can contact King's College London using the details below for further advice and information:

- Dr Mark Miodownik, Division of Engineering, King's College London, Strand, London, WC2R 2LS.
  Telephone: 020 848 2442 Email: mark.miodownik@kcl.ac.uk

King's College London Biomedical & Health Sciences, Dentistry, Medicine and Physical Sciences & Engineering Research Ethics Sub-Committee
BDM/2008/2009/2 11

Figure I.11: Page 11 of the form submitted to the Ethics Committee.



CONSENT FORM FOR PARTICIPANTS IN RESEARCH STUDIES

KING'S College LONDON

University of London

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Study: The Taste of Materials –Part 1: Spoons

King's College Research Ethics Committee Ref: BDM/08/09-74

- **Thank you for considering taking part in this research. The person organizing the research must explain the project to you before you agree to take part.**
- **If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.**
- ***I understand that if I decide at any other time during the research that I no longer wish to participate in this project, I can notify the researchers involved and be withdrawn from it immediately.***
- ***I consent to the processing of my personal information for the purposes explained to me. I understand that such information will be handled in accordance with the terms of the Data Protection Act 1998.***

Participant's Statement:

I ____

agree that the research project named above has been explained to me to my satisfaction and I agree to take part in the study. I have read both the notes written above and the Information Sheet about the project, and understand what the research study involves.

Signed **Date**

Investigator's Statement:

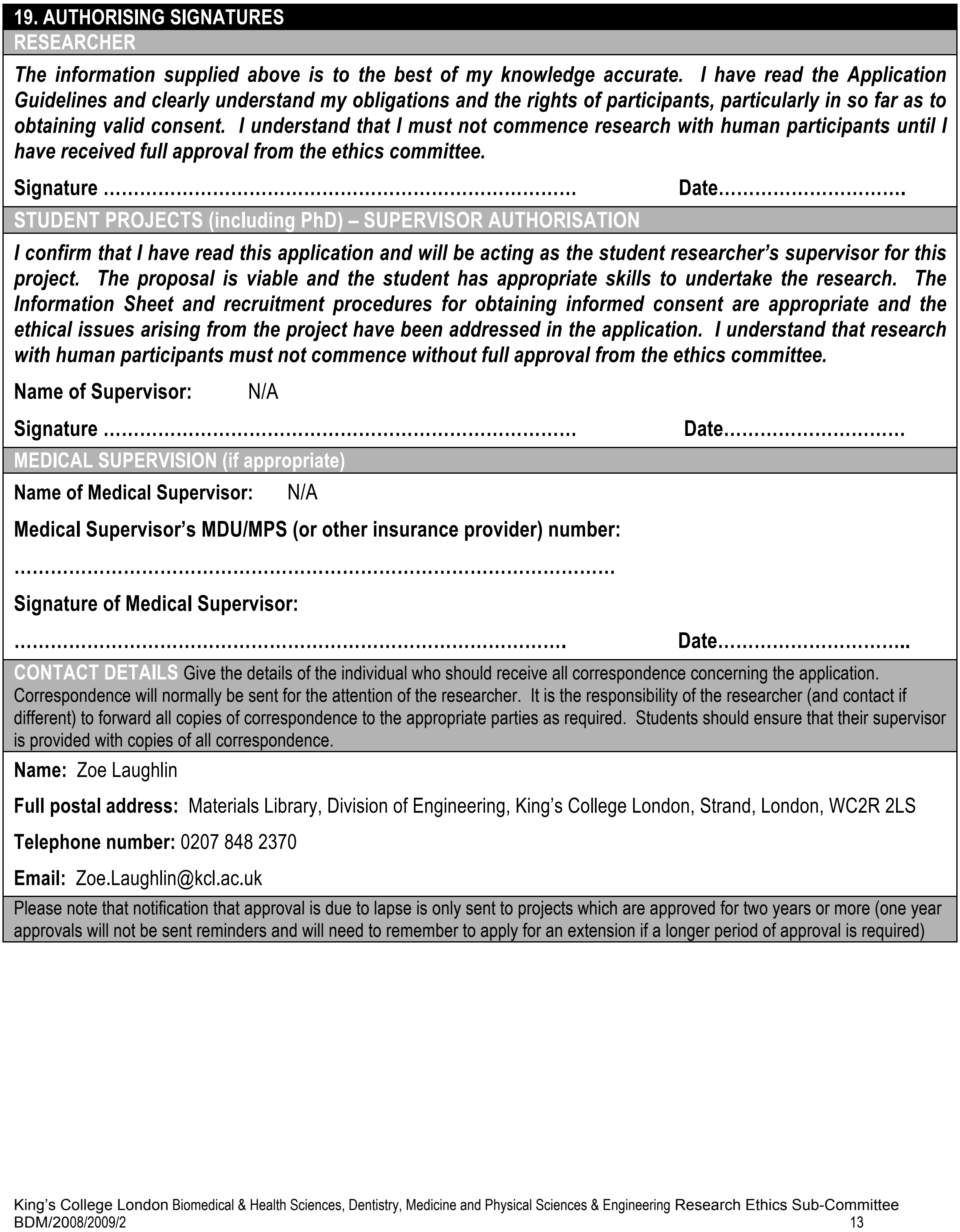
I ____

confirm that I have carefully explained the nature, demands and any foreseeable risks (where applicable) of the proposed research to the volunteer.

Signed **Date**

King's College London Biomedical & Health Sciences, Dentistry, Medicine and Physical Sciences & Engineering Research Ethics Sub-Committee
BDM/2008/2009/2 12

Figure I.12: Page 12 of the form submitted to the Ethics Committee.



19. AUTHORISING SIGNATURES

RESEARCHER

The information supplied above is to the best of my knowledge accurate. I have read the Application Guidelines and clearly understand my obligations and the rights of participants, particularly in so far as to obtaining valid consent. I understand that I must not commence research with human participants until I have received full approval from the ethics committee.

Signature …………………………………………………………………… **Date**…………………………

STUDENT PROJECTS (including PhD) – SUPERVISOR AUTHORISATION

I confirm that I have read this application and will be acting as the student researcher's supervisor for this project. The proposal is viable and the student has appropriate skills to undertake the research. The Information Sheet and recruitment procedures for obtaining informed consent are appropriate and the ethical issues arising from the project have been addressed in the application. I understand that research with human participants must not commence without full approval from the ethics committee.

Name of Supervisor: N/A

Signature …………………………………………………………………… **Date**…………………………

MEDICAL SUPERVISION (if appropriate)

Name of Medical Supervisor: N/A

Medical Supervisor's MDU/MPS (or other insurance provider) number:

………………………………………………………………………………………

Signature of Medical Supervisor:

……………………………………………………………………………… **Date**…………………………..

CONTACT DETAILS Give the details of the individual who should receive all correspondence concerning the application. Correspondence will normally be sent for the attention of the researcher. It is the responsibility of the researcher (and contact if different) to forward all copies of correspondence to the appropriate parties as required. Students should ensure that their supervisor is provided with copies of all correspondence.

Name: Zoe Laughlin

Full postal address: Materials Library, Division of Engineering, King's College London, Strand, London, WC2R 2LS

Telephone number: 0207 848 2370

Email: Zoe.Laughlin@kcl.ac.uk

Please note that notification that approval is due to lapse is only sent to projects which are approved for two years or more (one year approvals will not be sent reminders and will need to remember to apply for an extension if a longer period of approval is required)

King's College London Biomedical & Health Sciences, Dentistry, Medicine and Physical Sciences & Engineering Research Ethics Sub-Committee
BDM/2008/2009/2 13

Figure I.13: Page 13 of the form submitted to the Ethics Committee.

Appendix J

Glossary

Conjecture
A formal staging of physical encounter with materials or material-objects around a specific theme, experience or concept. Usualy presented within a given space or relational context and inviting participation in the form of touching, a Materials Conjecture, as an event, provides a physical interfaces with materials, facilitating conversations and allow haptic, olfactory and auditory engagement with matter. The word Conjecture was specifically chosen to reference its use in mathematics to describe propositions yet to be proven or disproved, and the work of Karl Popper who bought the term into the discourse of the philosophy of science (Popper, 2002). A Materials Conjecture is thus presented as proposition of experience to be investigated by those who engage with it.

Conjecturer
The person enabling, supervising and facilitating a conjecture, acting as the catalyst for reaction between materials and those encountering them.

Encounter
The physical coming together of person and material. A live physical experience that suggests an arrestment of the senses in a moment that makes one notice, realise or consider something outside of the usual.

Isometric Methodology
The making of sets of material-objects that are of equal dimensions. The classical methodology for swatch creation where form is kept constant.

Isomorphic Methodology
The making of sets of material-objects where any one aspect (form, function or material) can become the variable, resulting in the creation of overtly relational material-objects.

Material Conjecture
See Conjecture.

Material Encounter
See Encounter.

Material-Object
A descriptive term used to embrace and unite both materials and objects. The words ‘material’ and ‘object’ are purposely hyphenated to represent the status of each as being continually linked to the other –there is no matter without a form and no object without material. The term is also used to emphasis the conceptual nature of both materials and objects and demonstrate that once something exists it moves away from the concept of either, into a negation reality with both.

Material-Object Continuum
The dynamic space *along* which material-objects are located with the concepts of ‘material’ and

'object' providing the two ends of the continuum. Material-objects can traverse the continuum through changes in form or material, through isomorphic methods of material-object experimentation, to become more-or-less object or more-or-less material.

Material-Obejct Nexus
The dynamic space *within* which material-objects are located. The use of the word nexus is deliberately chosen to emphasise the relational connections that exists between material-objects due to similarities in material, form and function.

Performativity
Materials perform. Stuff is constantly getting up to things. Matter is doing all of the time, at varying scales of time and space, in order to exist and generate the world of objects. Reference to performance, the performative and the performativity of matter is done to draw attention to this –the agency of materials. With performance describing both the act and quality of a 'doing', it is embraced here as both a theatrical reference point and engineering qualifier. Imagine what would be considered as a high, poor or specialised performance material for either discipline.

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