THE POTENTIAL OF DNA STRUCTURE TO PROVIDE A RESOURCE FOR THE CREATION OF ART

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Thesis Abstract

Art's search for new subjects and methods and science's need for effective communication have led to the creation of what is known as Sci-Art. It is the central argument of this thesis that collaboration between creative and scientific disciplines can play a useful role in society, but that this potential is held back by misunderstanding of the roles of art and science.

The main purpose of this practice-based research project, which is also supported by a written thesis, is to determine the relationship between artists and scientists, focusing on the visualisation of DNA. The project will identify their shared approaches to its representation, and will explore the history of DNA as an iconic form. An additional purpose of this study is to analyse the importance of the role of collaboration between scientists and artists including its application to education.

My method is to review Sci-Art work and analyze the benefit of collaboration between science and art. Part of this research will focus on the benefits of Sci-Art collaboration for education. This part of the research involved a case study at Trinity Catholic School, with a project called *Laboratories*. Collaborative artworks and exhibitions are the final outcome of this project; they explore the ways in which Sci-Art can be developed as a useful form of interdisciplinary practice. These creative methods provide a route to a deeper understanding of the relationship between art and science.

The thesis demonstrates through a combination of theoretical argument and creative practice that Sci-Art has the potential to: Act as an aid to understanding difficult scientific concepts; add to debate about the ethical issues surrounding science and increase the effectiveness of education.

Acknowledgements

Thanks to Professor John Newling who is my direct of studies, Professor Simon Lewis who is my second supervisor, and Professor Richard Woodfield who was my second supervisor and retired in 2005. They are my masters and guide me to understand not only the world of art, but also the meaning of life since 2003.

Special thanks to Inchul Choi who is my private science teacher and criticized my thought with his different views on science and art. However, as my best friend, he supported me in many ways during my PhD course.

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Chapter 1

Introduction of Art and Science

1.0 Research questions

Since 1990, an increasing number of artists have been inspired by biotechnology and the social and moral issues that surround it. Sci-Art is the generic name given to artworks that use scientific concepts, images or technology. The purpose of this practice-based research project, which is also supported by a written thesis, is to determine the relationship between artists and scientists, focusing on the visualisation of DNA. The project will identify their shared approaches to its representation, and will explore the history of DNA as an iconic form. An additional purpose of this study is to analyse the importance of the role of collaboration between scientists and artists (referred to here as Sci-Art), including its application to education.

My research questions are:

- What are the differences and similarities in the visualization of DNA and biotechnology by artists and scientists?
- Why has the DNA structure become a cultural icon?
- What is the role of Sci-Art in contemporary society?

1.1 Outline of chapters

Each chapter of this thesis contributes to answering the research questions. The first research question will be covered in chapters 1, 2, 4 and 5. Chapter 1 will include discussion of the similarity and differences between art and science, followed by an evaluation of the benefits of Sci-Art collaboration. Chapter 2 explores the process of scientific innovation, focusing on Watson and Crick's discovery of DNA, and the ways in which they visualised its structure. In chapter4, I will discuss the visualization of DNA by scientists, and how drawing reflects their research interests. Chapter 5 analyses the visualisation of DNA by artists, and is categorized into five sections by their subjects: new portrait; mutation and monsters; transgenics; eugenics and commodity. The second question will be covered Chapter3. Chapter 3 examines DNA as an iconic structure and the factors that give it this iconic status. I will analyze the role of the relationship between images and society, particularly in the interactions between art and science.

The third question will be covered in Chapters 6 and 7. I will argue for the importance of collaboration between art and science in education. Chapter 6 will cover the analysis of Sci-Art questionnaires which were carried out with students from Trinity Catholic School. These two-part questionnaires were designed to explore: 1) the question as to how students regard science and art, and 2) their attitudes towards Sci-Art. Chapter 7 will introduce my own artworks, which represent science as a site or mediator of the beauty of nature. Informed by my analysis of Sci-Art collaboration, my artworks aim to provide a deeper understanding of the relationships between art and science, and the ways in which Sci-Art could be developed and progressed as a useful form of interdisciplinary practice.

1.2 Introduction

In this chapter, I would like to discuss the relationships between art and science. As Martin Kemp (2005, p. 308-309) pointed out, to generalise about the relationship is not so much hazardous as impossible because neither science nor art are homogeneous categories and they both deal with a number of aspects. Science ranges from the observed complexities of environmental biology to the unseeable dimensions of theoretical physics. Art extends from the figurative representations of nature to the elusive abstractions of conceptual art. Even if we take one subject, molecular biology, for example – or in particular, DNA – its expansion into art may vary from iconographical reference to reflection of biotechnology on our future.

In this aspect, I believe that both art and science should be considered as a very powerful ‘engine’ in our culture. Thus, it could be argued that we still need to research in terms of interdisciplinary aspects. For example, Lizzie Burns, a painter who was formerly a biochemistry researcher at the University of Oxford, comments that much has been written about linking art and science, but that it is very difficult for each discipline to understand each other (Fazackerley 2004).

This is possibly because some people are frightened of science's developments in biotechnology.

However, pictures and models can make things easier to understand. Burns suggests that we really need to encourage the public to get involved with projects about art and science. Because these projects are mostly supported by taxpayers' money the public should know where it is going (Fazackerley 2004).

I strongly agree with her view. Plainly one of the roles or aims of Sci-Art is the collaboration between science and art as a tool to help with the understanding of science. There are also other benefits to be had through interaction between artists and scientists. To explore this relationship, I will begin with an attempt to define art and science respectively. Further sections of this chapter will determine what the kinds of benefits are, and establish the relationship between art and science.

1.3 Definition of Art and Science

There are a number of definitions for art and science in dictionaries. In summary, art and science can be described as follows: definitions compiled from The Shorter Oxford English Dictionary on historical principles (1989), Webster's Revised Unabridged Dictionary (1913), The American Heritage (2000).

Art is defined as:

1. Human effort to imitate, supplement, alter, or counteract the work of nature
2. The production of the beautiful in a graphic or plastic medium
3. Human works of beauty considered as a group
4. High quality of conception or execution, as found in works of beauty; aesthetic value.
5. A non-scientific branch of learning; one of the liberal arts

Science is defined as:

6. Knowledge; knowledge of principles and causes; ascertained truth of facts.

7. Accumulated and established knowledge, which has been systematized and formulated with reference to the discovery of general truths or the operation of general laws; knowledge classified and made available in work, life, or the search for truth; comprehensive, profound, or philosophical knowledge.
8. Knowledge when it relates to the physical world and its phenomena, the nature, constitution, and forces of matter, the qualities and functions of living tissues, etc.; called also natural science, and physical science.
9. Art, skill, or expertness, regarded as the result of knowledge of laws and principles.

There is a marked contrast between art and science by these definitions. According to these definitions, we assume that art is based on skill and science is based on knowledge. It is interesting to look at one of the definitions of art which is a non-scientific branch of learning and one of the definitions of science describes that science is art, skill, or expertness, regarded as the result of knowledge of laws and principles.

There is an overlap of definitions between art and science. Therefore, to understand art and science better, we need to consider the relationship between them. According to Ernst Fischer, art historian and philosopher, the historical origin of art and science lies in the ritual of everyday living. In his book *The Necessity of Art* (Fischer 1959), Fischer says that in ancient times these rituals were performed to mediate between human life and the uncertainties of world. But in more modern times, the unified domain of art and science became isolated and divided, and each established its own distinct domain (Fischer 1959, p. 36).

The question arises as to why the boundaries are maintained between art and science. The practical usefulness of knowledge through science can be seen as one of the reasons for divergence, but it is not enough to answer the question as to why the two domains should remain separate. Therefore the following section addresses the similarities and differences in art and science.

1.4 Similarities in the Aims of Art and Science

When it comes to the content of art and science, the overlap of science and art is admittedly very small. This is because modern science is abstract, impersonal, reliable and empirically tested whilst art is individualistic and offers us an alternative, legitimate and personal take on reality (Carey 2005). It is worthwhile now to look at some real areas of common concern and overlap. Piet Mondrian, known as 'the father of geometric abstraction', was the artist who simplified visual compositions to the vertical and horizontal directions. In 1937, he wrote:

> **For there are "made" laws, "discovered" laws, but also laws – a truth for all time. These are more or less hidden in the reality which surrounds us and do not change. Not only science but art also, shows us that reality, at first incomprehensible, gradually reveals itself, by the mutual relations that are inherent in things (Miller 2000, p. 379).**

As mentioned above, Mondrian wrote that the both art and science present reality. The reality of science is different from art which can be gradually found in the understanding of humans and culture and might be constant. This kind of reality can be seen in various artworks in art history. Mondrian was himself inspired by science, deploying some of that inspiration in his abstract paintings.

Stephen Wilson's analysis in his book, *Information Arts* (2002), is useful for understanding these similarities and differences. First, he explains the similarities by which art and science propose to introduce change, innovation, or improvement over what exists (Wilson 2002, p. 18-19). They also both use abstract models to understand the world based on the careful observation of their environments. According to Ken Arnold, who is head of public events at the Wellcome Trust, intellectual curiosity for the natural world is what artists and scientists have in common with each other.

> **Both art and science are essentially ordering activities, part of the universal human inclination to find, expose and celebrate the world's structures and patterns. Even more fundamentally, they gesture towards the fact that both art and science are expressions of a common intellectual curiosity- the profound human desire to know things, which often starts with the possibility of envisioning and therefore of making a picture of them (Arnold in: Ede 2000, p. 68).**

Art historian Martin Kemp also shares this opinion of the similarities between art and science. In his book *Visualization (2000)*, he suggests that there are many similarities to be found in the process – rather than their end products – of art and science. Examples include observation, structured speculation, visualization, exploitation of analogy and metaphor, experimental testing. In particular, Kemp points out that visualization plays a central role in both disciplines, in their use of imagination, inspiration and creativity (Kemp 2000, p. 4).

In my opinion, creativity is a shared value of those aspiring to produce something of universal relevance. Both art and science are ways of understanding and representing the world, and both must involve creativity in order to succeed. They show us how to analyse and communicate our perceptions, experiences, and can inspire us and consequently enrich our imagination.

1.5 Differences in Aims between Art and Science

Stephen Wilson suggests that a reason for the differences between art and science is that art seeks *aesthetic responses* by using visual or aural communication (Wilson 2002, p.18-20). Artists try to express emotion and intuition, and so art can be seen as being evocative and even idiosyncratic. Science, on the other hand, seeks knowledge and understanding using logic and reason, therefore science can be seen as explanatory. Alan Lightman, a physicist and professor of humanities at the Massachusetts Institute of Technology, explained the differences in this way:

> **There are questions with answers and questions without. Scientists work on questions with answers. Although science is constantly revising itself in response to new ideas and data, at any moment each scientist is working on what is called a well-posed problem-that is, a problem of such a kind and stated with such clarity that it is certain to have a definite answer. That answer may take ten years to find, or a hundred, but an answer exists. By contrast, for artists the question is often more interesting than the answer, and often an answer doesn't exist (Lightman, 2005).**

According to Lightman, the difference in art and science is that science involves well-posed problems and a degree of certainty. In other words, scientists may have methods developed for certainty, while artists may develop methods for uncertainty. It means that scientists are focusing on 'how', while artists prefer to raise the question 'why'. For example, in the Human Genome Project, scientists have determined how the human genome has evolved differently to other species, but artists have tried to express their thought through more philosophical approaches, based on themes such as identity, genetic determinism or eugenics. Sian Ede also agrees that

> **Scientists, whatever their field of study, are governed by 'the scientific method' and in investigating how the world operates theirs is a shared search for agreement; contemporary artists work alone, they make things up and encourage individual or even dissenting responses (Ede 2000, p. 30).**

Here Ede points out the difference between scientists and contemporary artists, who continue to ask the questions without answers. In this sense, artists can identify and express questions in their art work. For instance, John Newling, a well known artist and professor of Fine Art at Nottingham Trent University, had an installation project "Stamping Uncertainty" at the chapter house in Canterbury Cathedral in 2004. He concentrated on the number of questions which are confessions of uncertainty. Andrew Spira offers this interpretation of Newling's questions:

> **The questions are confessions of uncertainty but, perhaps more importantly, they provide a form of relationship to the unknown, maintaining a circuit of energy and attention between the doubtful mind and the possibility of understanding (Newling 2004, Foreword).**

Jacques Mandelbrojt also shares the opinion that scientists have to beware of the mistakes their imagination can induce, because the aim of imagination is to explain real facts, whilst imagination in art is never wrong because imagination does not have to confront its image with reality (Mandelbrojt 1994).

1.6 Artists and Scientists' interpretation

As mentioned above, both creativity and imagination are crucial elements in art and science. However, two disciplines are also apparently different in terms of their *usage* of creativity and imagination. In order to understand the similarity and difference of the arts and sciences, it is necessary to explain the role of interpretation in art and science. The distinguished King's College London embryologist Professor Lewis Wolpert asserts that

> **Moreover a work of art is capable of many interpretations and has moral content. There is but one correct scientific explanation for any set of observations and reliable scientific understanding has no moral or ethical content. Art is a personal creation and contains the personal views of the artist but whatever the feelings of the scientist these are absent from the final understanding of a process (Wolpert, 2002).**

Wolpert (2006) points out that art and science both involve interpretation, but in science only one interpretation should be correct whilst there are various interpretations in art because artworks also include subjective aspects such as moral issues and emotion.

Interpretation can explain some of the differences that exist between art and science. Scientific interpretation is used to analyse data given by observation in order to logically prove a hypothesis. In art, artists interpret the world about them in all its physical, social and spiritual aspects which described not just factual but also aesthetic reality. That is, both science and art, despite the similarities in their creative sprit, have radically different methods. So interpretation is a fundamental or basic element that can be used to understand the differences and similarities in art and science.

For that reason, it is necessary to further consider the understanding of interpretation. How might interpretation be used to unite the knowledge of art and science? Can interpretation be the logical channel to link between art and science? Or can it not, because the gap between art and science originated from differences in interpretation?

1.7 Comparing Artistic Sculpture and Scientific Models of DNA

Obviously, there are differences between artistic and scientific models. Scientific models of DNA function as an indexical sign to explain the information interpreted using analysed data. The interpreted model succinctly represents hypotheses or theories, and the structure is comprehended by the scientific community or public to give the same information. In contrast, artistic representations of DNA can be differently described and interpreted. For instance, artists do not need to describe the structure as precisely in order to illustrate the analysed information. Sculpture is an index and a mirror, reflecting artists' own experience and social meaning about the structure (Wayne et al, 1996).

Harold Osborne describes his interpretation in a paper:

> **The basic meaning of interpret is, then, to elucidate or verbally to unfold or disclose the information encoded in any communication be it in written or spoken words, gestures, smoke signals or pulses of light from a laser beam […] considerable modification is necessary in connection with the**

fine arts. Interpretations of works of art are valued, not so much for correctness, as for their validity and perspicacity (Osborne 1986).

However, there still remains the question of whether interpretation can be used as a bridge between art and science. In their interpretation of the same object, it is my opinion that there are 'rooms' that can be shared by both artists and scientists. Through collective interpretation processes, both art and science could learn from each other in terms of inspiration and practical breakthroughs. Furthermore, a union of the two disciplines might allow the public to engage in the relationships between art and science.

1.8 Art, Science and the Public: Building the Triangular Bridge

Since DNA's double helix structure was discovered, there has been a biological revolution based on DNA technology, which has changed aspects of our lives in political, medical, ethical and legal territories. As S. Mawer (2003) wrote, "*DNA has now escaped the laboratory and infected the whole world. We are in the midst of a pandemic.*" In this sense, DNA is a regular presence in films, novels and advertisements (this will be discussed in more detail in chapter 3). Furthermore, there are numerous visual artists that have been inspired by modern biology such as molecular and cellular biology. Such artists include Suzanne Anker, Eduardo Kac and Dennis Ashbaugh.

However, today's general public cannot grasp the specialised knowledge of contemporary science and technology. This can lead to general confusion, denial or dread about scientific developments. To rectify this problem, some organizations and governments have tried to achieve a balanced and informed view of scientific and societal dilemmas in order to minimise the gap between scientific revolution and public understanding.

Tamar Schlick (2005), professor of chemistry at New York University, suggested that the gap can be filled by collaboration between artists and scientists. If this is true, this method of collaboration could be a valuable path towards understanding between the two cultures. It is important to take a look at the background and current status of the collaboration between art and science.

Much of the discussion concerning art and science can be traced back to C.P. Snow's famous Read lecture at Cambridge on 7th May 1958, "The Two Cultures and the Scientific Revolution" and his subsequent book based on the lecture (Snow, 1963). In this book, he wrote :

> **The clashing point of two subjects, two cultures-of two galaxies, so far as that goes-ought to produce creative chances. In the history of mental activity that has been where some of the break-throughs came. The chances are there now. But they are there, as it were, in a vacuum, because those in the two cultures can't talk to each other. It is bizarre how very little of twentieth-century science has been assimilated into twentieth-century art (Snow 1963 p. 16).**

Snow stressed the significance of the lack of communication between sciences and arts, which might be likely caused by intrinsic or methodological differences of two cultures. He warned that the gulf between two academic cultures was getting so wide that they could not easily communicate with each other, to the detriment of public interest. The two cultures he described were those of the literary intellectuals and the scientists.

Snow (1963) also pointed out that the gap originated from the specialisation of science compared to the science of previous periods. For this reason, even scientists also had difficulties in understanding other fields of science. The more the sciences develop and specialise, the more the public cannot understand the discoveries of sciences.

What about the methodological differences in art and science? The scientists are not able to accept the necessity of raising the type of questions that artists deal with. With regard to this matter, Snow argued that two cultures should progress with each other. To achieve this, he suggested that students majoring science should learn arts and *vice versa*. Through this method, students can understand 'why', and 'how', and consequently, it could fill the gap between two cultures. In this sense, I believe that Sci-Art can be one of the methods to fill the gap.

On the role of art as a 'bridge' for the painful communication gap, Victoria Vesna, an artist and educator at the University of California in Los Angeles, shared with Snow the view that artists are in a position to play a critical role in understanding communication between artists, scientists and the public:

> **The bridge, in fact, is being triangulated and made more stable with the work of artists utilizing new technologies, who are in active dialogue with both sides. Artists using technology are uniquely positioned in the middle of the scientific and literary/ philosophical communities and are allowed poetic license, which gives us the freedom to reinforce the delicate bridge and indeed contribute to the creation of a new, mutant third culture (Vesna, 2001).**

However, Lewis Wolpert takes a very different view:

> **Although science has had a strong influence on certain artists - in the efforts to imitate nature and thus to develop perspective or in the area of new technologies - art has contributed virtually nothing to science (Wolpert 2002).**

Wolpert argues that art and science are so different and not two cultures as pronounced by C. P. Snow. Wolpert argues that art is valued on its own terms but it has nothing to do with science although science had a strong influence on certain artists. It has been argued that science provides explanations rather than viewpoints and, compared with art, it requires for its appreciation a much greater and quite different intellectual effort (Wolpert, 2006). This is not to say that art has never aided science. Wolpert is marking out a boundary like a membrane through which "ideas from science spill into art, but the reverse does not happen" (Webster, 2002).

Admittedly, we can not say Wolpert's opinion is totally wrong, particularly because art has been affected by science, and because many examples of artworks inspired by science can be found in art history. According to Rhonda Roland Shearer, in art there are two large scale developments affected by scientific revolutions: One example is the discovery of perspective in the Renaissance, and another is the birth of modern abstract art. Especially at the beginning of 20th century, artists like Marcel Duchamp and Naum Gabo were familiar with the new geometries which were popularized during the late nineteenth and early twentieth centuries (Shearer 1996).

Albert Einstein's theory of relativity was also inspired by the new non-Euclidean geometries, which describe the geometric properties of alternative conceptions of space. For example, in hyperbolic and elliptic geometry, parallel lines diverge or converge respectively, in contrast with Euclidean geometry (see Figure 1).

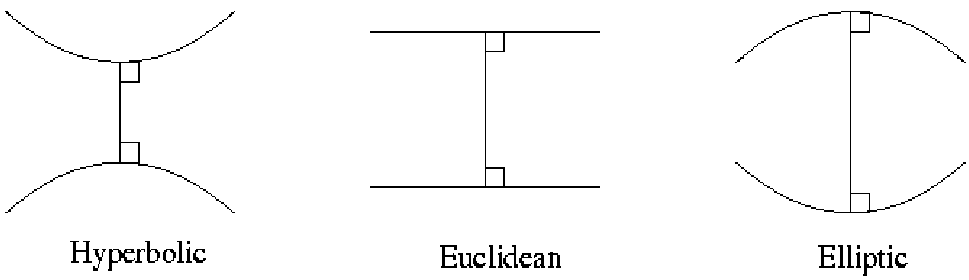


Figure 1. Behavior of parallel lines in three types of geometry

Non-Euclidean geometries and in particular elliptic geometry play an important role in Einstein's relativity theory which was published by Einstein in 1915. The non-Euclidean geometries were inspirational to artists, especially the cubist approach presented by Georges Braque and Pablo Picasso in 1907. This approach was quickly joined in the 1910s by various other movements, including Constructivism, De Stijl, and Futurism. Their geometric forms began, effectively, when the solidarity of the old disciplines (Formalism) broke down in the interests of a new form and a scientific revolution.

But the relationship between art and science is a little more complex than Wolpert allows. As mentioned earlier, the more science advances, and the greater its influence is in our society, the more questions are raised about the influence of science to our society. The reason for this is that scientists not only discover more about nature (pure science), but they can also imitate nature (applied science) such as genetic modification or cloning technology. These new technologies offer potential benefits such as increased crop yields, but the public have concerns over the safety of such products, or simply disagree in principle. Therefore, scientists should not avoid the ethical issues raised by such technologies, and Sci-Art could help to highlight these issues and open the debate.

Artists have begun to express their opinions of ethical scientific issues through their artworks. Wolpert (2006) argued that art has had no effect on science research. However, when it comes to an artistic approach (i.e. not pursuing the 'correct' answers, but raising questions and communicating the public), is this really true? Wolpert's assertion is true in the case of pure science, but he fails to consider the impact of visual art on applied science and biotechnology and their ethical issues.

Lynn Gamwell, director of the Art Museum at the State University of New York, pointed out that recently many artists have explored such questions which have been raised by applied science or biotechnology (Gamwell 2003). I believe that artists are interested in these subjects because of the social and moral issues that they raise within our culture. Thus, the work of Sci-Artists, who attempt to build these bridges between science and the public, can be seen as evidence against Wolpert's statement. However, these bridges are not all equally useful in this respect – they can be positive, negative, experimental or merely superficial. The most important role for Sci-Artists is that they use artwork to communicate with the public and enable public discussion of social or moral issues raised by scientific research.

The arguments I have presented for the role of Sci-Art are not simply a theoretical view. I am also putting this theory into practice by making artworks with the intention of building a bridge to scientific understanding. One example of this work is my art exhibition in BioCity, Nottingham in 2005 (chapter 7 figure 45-46). BioCity is a bioscience incubation centre helping to develop this industry in the East Midlands by creating a hub of activity to aid networking and develop business. Visitors to the exhibition had the opportunity to view these reliefs and sculptures, which were displayed in the public room and on the central landing of the BioCity premises. The audience for the exhibition at BioCity includes students and school children, as well as visiting clients and the staff of the many small businesses within the organisation.

One of the aims of this artwork was also to improve the overall attractiveness of the environment at BioCity and to encourage more people to come into and linger in the building. The feedback from the staff at BioCity was very encouraging: some said the artworks made them happier to work within the building; others said the work offered an unexpectedly engaging artistic experience within the context of a more ‘dry’ scientific environment. The CEO of BioCity Nottingham Ltd, Glenn Crocker, expressed his opinion of my art exhibition in an exhibition pamphlet as follows:

> **Art can lift an otherwise sterile environment; it can initiate discussion and debate and it can inform and educate: this can contribute greatly to some of the challenges facing science and its public perception. It is particularly appropriate that Seong’s work explores the DNA revolution that gave birth to the biotechnology industry which is being supported here at BioCity (Kim 2005, foreword).**

Another example of my efforts to bridge the gap between science and the public was my exhibition of *Life is Endless Desire* at the Korean Science Festival in 2005 which was organized by the Korean Science Foundation. The purpose of the project was to collaborate with the scientist Professor Keith Campbell and design lecturer Anthony Crabbe, to demonstrate to the public how artworks can evoke meaningful speculation about science. Keith Campbell is one of the scientists involved in the creation of Dolly the sheep, which was the first animal cloned using somatic cell nuclear transfer. My exhibit focused on the structural model of DNA, with the aim of encouraging debate about genetic engineering among the general public.

In an interview with *The Science Times*, Cambell said that the aim of attending this exhibition was not for scientific work, but to become involved in art as a different method of communication and understanding. He mentioned that art is a suitable method for introducing science, because he believes that it can offer a more accessible route to scientific understanding (Kim 2005). Also, Crabbe pointed out the importance of the role of Sci-Art in his foreword for the exhibition:

> **We may imagine that however much a parent is told that the nature of her child has been fixed by genes, her desire will always be to furnish the experience most likely to change her child for what she reasons to be best. Art is in some sense similar. It may not set the agendas for society in the way that science does, but it persists in behaving as if it could enable its viewers to amend those agendas (Kim 2005, foreword).**

We gave several lectures at the exhibition and at some Korean universities, and were part of a science TV programme on Korean television. The documentation of this work provides support for the argument in this thesis for the value of art as a bridge to understanding. Further details of the people and processes involved in the exhibition's creation will be documented later in chapter 6.

1.9 Conclusions

In summary, artists interact with science in three ways. Firstly, artists have been inspired by scientific images found in journals and text books. Examples include: *Butterfly Landscape, (the great masturbator in surrealist landscape with DNA*), (1957-1958), oil on canvas, Salvador Dali; *Designer Gene* (1992), stained DNA images on gel, Dennis Ashbaugh; and *Material Powers* (1999), glass, steel & water, Suzanne Anker.

Secondly, artists started to collaborate with scientists to realise their concepts. For example, Eduardo Kac created transgenic artwork by inserting green fluorescent pigment (GFP) from a jellyfish to a rabbit in his work, *GFP Bunny* (2000).

Thirdly, artists may collaborate with the public to make artworks on science subjects and scientific issues, in activities sponsored by institutions such as the Arts Council or the Wellcome Trust in the U.K. and the Korean Science Foundation in Korea. These efforts can be considered as a bridge to link science and the public.

However, the gap between them is still wide because each discipline takes different paths. So, we inevitably need to fill this gap in knowledge. To address the problem of this gap between the two disciplines, it is necessary to consider the collaboration of art and science in education. From an early age, students should have more opportunities to learn the relationship of the two different disciplines. In this way, collaborative art work with students about science subjects can provide another bridge. In short, the more bridges, the better communication.

The next chapter will explore how scientists interpret observed data, focusing on the discovery of DNA structure and the ways in which they visualised its structure. It will view the relationship between scientific discovery, imagination and creativity.

Chapter 2

Discovery of DNA Structure by Watson and Crick in 1953

2.0 Introduction

As DNA is a central motif in both this thesis and in my artwork, this chapter will describe the history of how its structure came to be visualised. This is important because artists need to understand their subjects in order to explore in deeper ways. According to Martin Kemp, artists who use a scientific subject in their artworks should have a thorough understanding of scientific knowledge in order to successfully build a bridge between art and science:

> **Too many of the increasingly fashionable art-science initiatives seemed to me to be operating at a surface level, in which obvious points of contact (e.g. artists using scientific imagery) were simply narrated or in which objects from art and science were juxtaposed without really interpenetrating (Kemp 2000, Preface).**

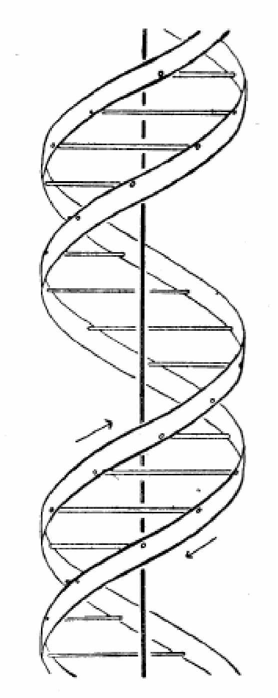
I strongly agree with Kemp's opinion, and I have made efforts to reach such a deep understanding of the area of genetics and molecular biology, with a particular focus on DNA structure. My interest in DNA began when I married Dr. SeogHyung Kim, who is a genetics scientist, and this gave me an opportunity to engage with a scientific field. I started making artworks whose form was based on DNA structure and whose content was concerned with the moral issues around subjects such as cloning. Even during my MA course in 1996-97, I did not have a deep understanding of DNA and its associated technologies. However, I was determined to gain more knowledge about DNA and the discovery of its structure in order to create artwork for my doctorate. I do believe that if an artist intends to collaborate with scientists, it is useful to know more about their research and how scientists approach problems.

In this following section, I will describe the three-dimensional structure of DNA, the history of its discovery, and the relationship between scientific interpretation and visualization in science. It is important to realise that the scientific interpretation of data is closely related to imagination and creativity, as was argued in the introduction. Throughout this chapter, we will examine the interpretations of Watson and Crick and the importance of the role of visualization in their work.

2.1 DNA structure

On 25 April 1953, in an article, *A Structure for Deoxyribose Nucleic Acid* (*Nature 171, 737-738),* Watson and Crick published their outline of DNA (deoxyribonucleic acid) structure. In the same issue were papers by Wilkins and Franklin showing X-ray data of nucleic acids. The Watson and Crick paper was very brief, with about only 900 words and a single illustration. This short article with a purely diagrammatic figure provided the foundation for understanding the molecular and genetic mechanism of living organisms. Their discovery allowed for further breakthroughs, including the understanding of protein synthesis, hereditary disease, the behaviour of virus, and genetic engineering. Furthermore, the double helix figure has become an icon that is found in art, music, film, stamps and coins.

The most important feature of DNA is that it forms the shape of a double helix, as shown in figure 2a. This helical shape is made up of polynucleotide chains (see Figure b). The long, unbranched polymer chains are composed of four types of subunits called deoxyribonucleotides containing the bases adenine (A), cytosine (C), guanine (G) and thymine (T). The backbone of each chain is an alternating polymer of deoxyribose sugars and phosphates (Watson et al., 2004).



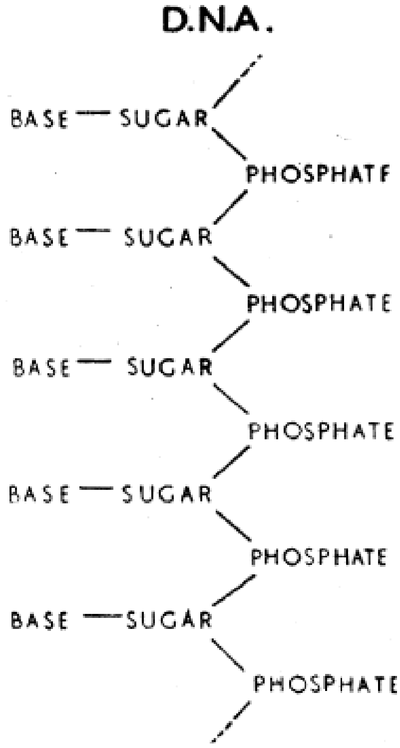


Figure 2a Structure of DNA drawn by Odile Crick, in *Nature*, 25 April 1953. **Figure 2b** Chemical formula of a chain of deoxyribonucleic acid

Another crucial feature of the DNA structure model is that all of the bases are on the inside of the double helix with specific pairing: G pairs with C, and A pairs with T, with each base pair forming the ‘rungs’ and the sugar phosphates on the outside forming the sides of the DNA ‘ladder’.

A significant feature of the double helix in DNA structure is that the two base pairs show the same geometry despite their differing composition, meaning that the space and distance between two sugars is enough not to perturb the arrangement of the sugars. Lastly, hydrogen bonding is important for the specificity of base paring and the thermodynamic stability of the helix, which provide structural stability and maintenance of the double helix structure (Watson et. al., 2004 p101).

The discovery of the DNA double helix is a milestone because the structure immediately suggested how genetic information could be precisely copied and transferred from each cell to its progeny.

2.2 History of the Visualization of DNA Structure Before 1953

I will begin this section by describing the chemical structure figures and diagram in DNA before 1953. Before I discuss the interpretation of the DNA double helix structure by X-ray diffraction photography, I will introduce the development of structural molecular biology. When a biochemist or a structural biologist draws the chemical structure of a substance on paper, the structure actually exists in three dimensions but is presented in two-dimension. The gap between actual property and presentation on paper in two-dimension is needed to fill up with three-dimensional figures.

To do this, a biochemist can learn about two important ways; one is to apply a physical tool from which scientists can deduce the relative spatial positions of the atoms in the DNA molecule. Of them, the X-ray diffraction is the most powerful technique. The other is model building based on parameters by calculation and observation using biochemical and physical tools such as titration and X-ray diffraction.

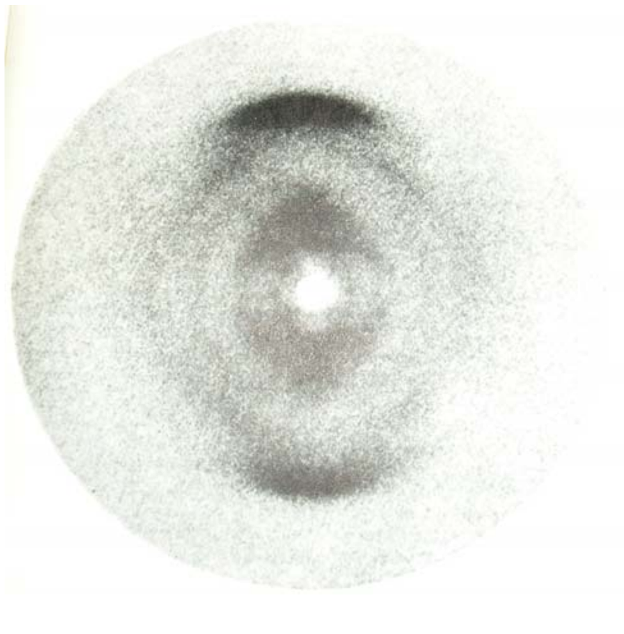


Figure 2 First X-ray diffraction photograph of a stretched dried film of DNA, published by Astbury and Bell (from Cold Spring Harbor Symposium on Quantitative Biology 6:112, 1938).

Figure 2 (Astbury and Bell 1938) shows a diagrammatic representation of DNA structure proposed by Astbury and Bell derived from X-ray studies in 1938. It was the first study of DNA based on X-ray diffraction photography. Astbury and Bell deduced a general structure of nucleotides from their photographs, and drawings like Figure 3 simply represent their conception of a pile of planar nucleotides.

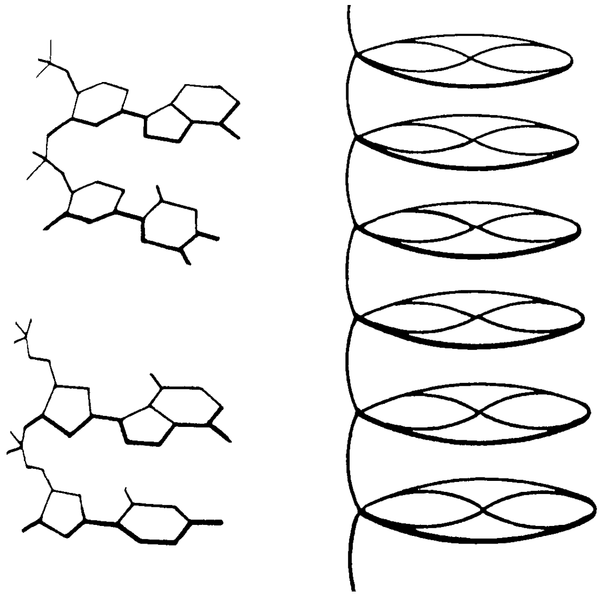


Figure 3 Structures of DNA proposed by Astbury and Bell; from Cold Spring Harbour symposia on Quantitative Biology 6, 114 (1938).

Furberg suggested two models of DNA based on nucleotides in the standard configuration. As can be seen in Figure 3, the planes of the purines and pyrimidines are perpendicular to the plane of the paper, packing together nucleotides of the standard configuration (but as noted above, the diagram is not entirely accurate because it only shows a single helix). We can image and draw the three dimensional single-stranded structure of DNA on paper (Figure 4); location of hydrogen, carbon, oxygen, and phosphorus (Furberg 1949).

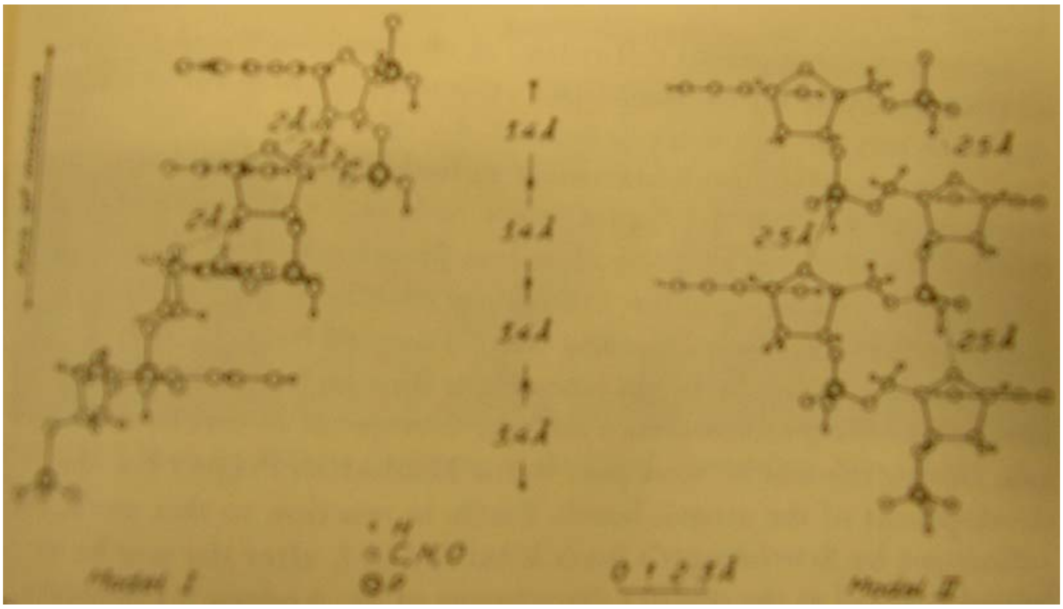


Figure 4 Two models of DNA based on nucleotides in the "standard configuration". The planes of the purines and pyrimidines are perpendicular to the plane of the paper (Drawing by S. Furberg from " A century of DNA").

Discovery of X-ray diffraction by crystals was revolutionary in understanding the structure of molecules. In 1920, there was one of the breakthrough discoveries in this field. R.O. Herzog and his assistant obtained the X-ray diffraction pattern of a natural fibre. The pattern with spots indicating a degree of regular structure along the axis of the fibre was solved by Michael Polanyi. He introduced several concepts that were to remain a basis for interpretation in this field (Portugal and Cohen 1977, p. 207, p. 235).

The elucidation of DNA structure via the nucleotide structure depends on more detailed X-ray diffraction photographs. Maurice Wilkins and Rosalind Franklin at King's College, London contributed to this field. Wilkins wanted highly polymeric DNA to study the orientation of the base. To obtain the sample materials, he observed that fibre had been produced unwittingly and obtained a thin and almost invisible fibre of DNA like a filament of spider's web by touching the DNA gel with a glass rod and removing the rod. He thought that the fibres might be excellent objects to study by X-ray diffraction because the molecules in the fibres were regularly arranged. He took the sample to Raymond Gosling who used it to obtain a very encouraging diffraction photograph (Figure 5a).

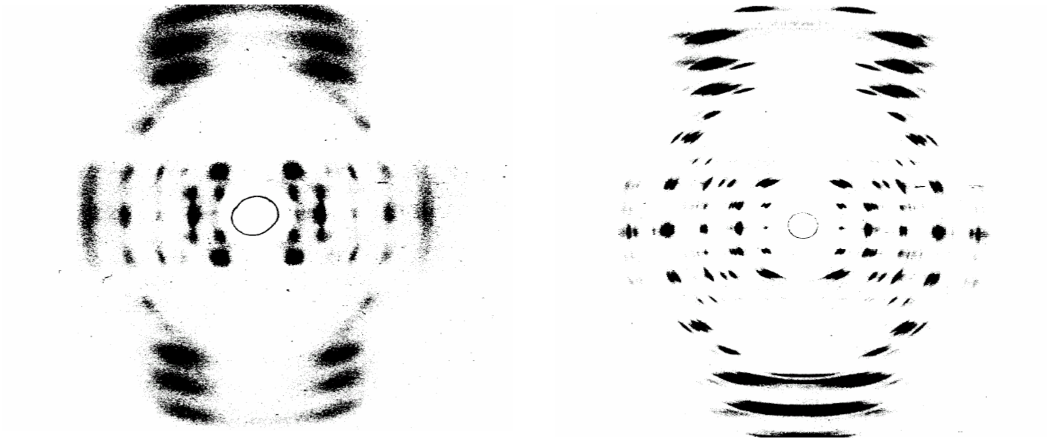


Figure 5 X-ray diffraction pattern of the A form of DNA. **a** the first X-ray diffraction photograph with R. Golsling. 5**b** A good photograph with H. R. Wilson. (http://nobelprize.org/medicine/laureates/1962/wilkins-lecture.html)

In contrast to the dried film of DNA employed by Astbury, the moist fibres are the key to elucidating the DNA structure. When the sample material with the high humidity gave a beautifully clear and detailed diffraction pattern termed crystalline (Figure 5b). In 1951, Wilkins theorised that DNA had helical characteristics from the X-ray diffraction pattern photograph. The theory was developed to explain the pattern in terms of Bessel functions.

The importance of this theory was to predict the absence and presence of certain reflections which appeared as spots in the X-ray photograph, because the precise location and intensity of these spots depended on the physical parameters of the helix such as pitch and diameter. As can be seen in Figure 6, the diffraction pattern of spots shows the presence of helix, and the molecular dimension of DNA could be deduced from the cross pattern (Portugal and Cohen J. S 1977, p. 207, Dickerson 1964).

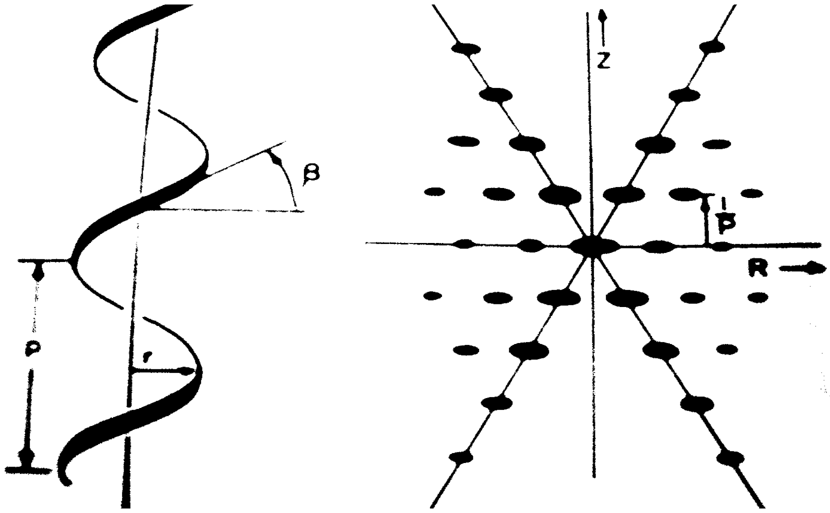


Figure 6 Diffraction pattern due to a helix, P; pitch, r; radius, beta; pitch angle, R and Z; coordinate axes (Dickerson R. 1964)

Franklin had a correct view of the nature of DNA structure. She realised that B form was helical from the careful measurements of the density of the sample and water content (Franklin and Gosling 1953). In 1951 people favoured three chains rather than two chains per DNA molecule. However, she could not represent her view because she wanted to show ample and clear evidence to support the interpretation of her results.

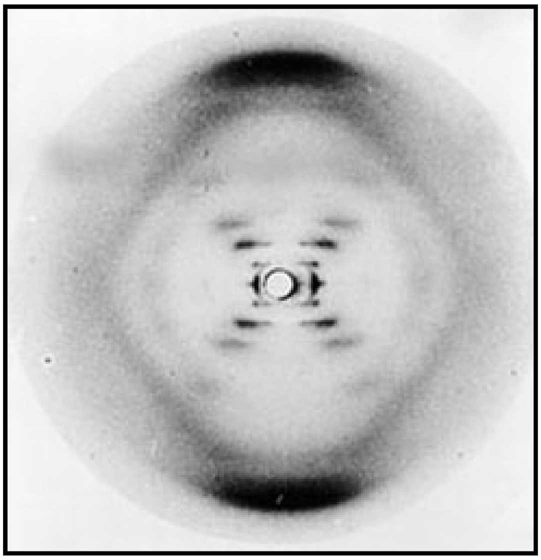


Figure 7 Photograph by X-ray diffraction, B form of DNA (R. E. Franklin and R. G. Gosling, 1953)

2.3 History of the Visualization of DNA Structure After 1953

Watson and Crick performed no experiments themselves. Instead their tactic was to summarise other groups' data known by February 1952 to construct their model of DNA structure in 1953. X-ray diffraction photographs were very impressive to them. In this X-ray diffraction pattern, they were able to calculate the actual distance between the horizontal bars. They also calculated the helix's pitch from the angle seen in Figure 8.

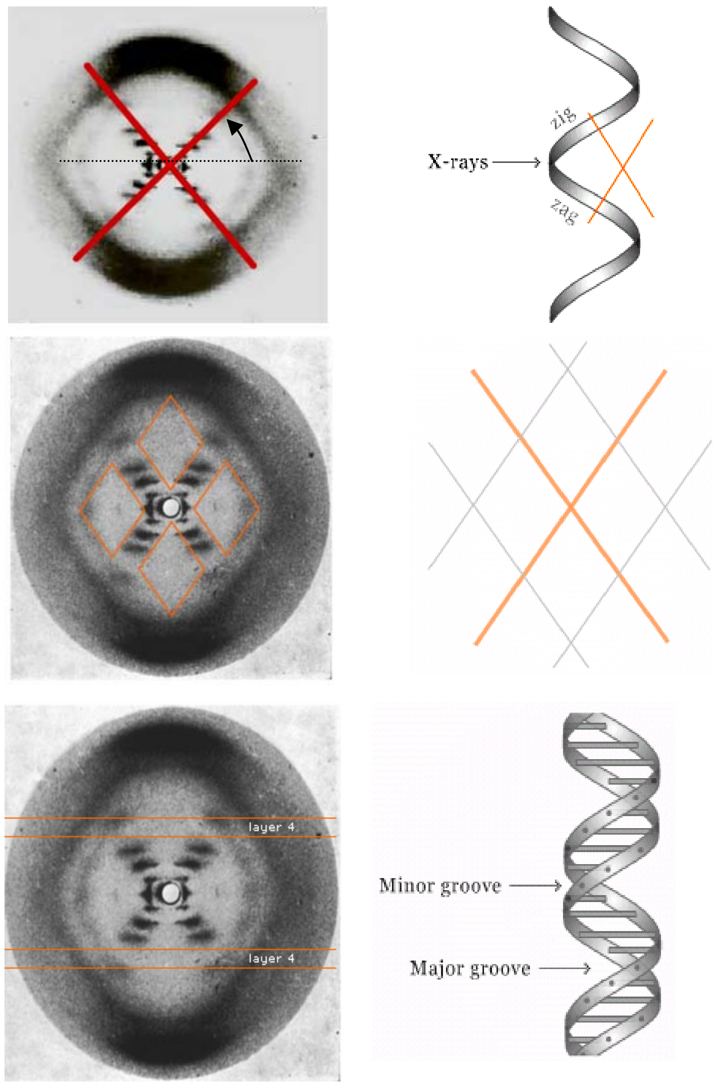
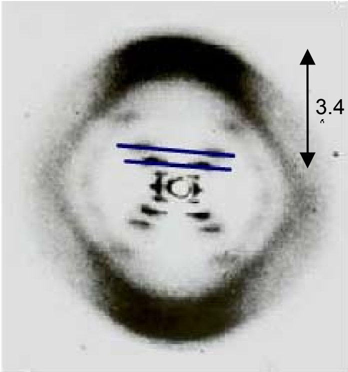


Figure 9 Interpretation of X-ray diffraction photographs.
(http://www.pbs.org/wgbh/nova/photo51/;http://www.dnaftb.org/dnaftb/19/concept/index html).



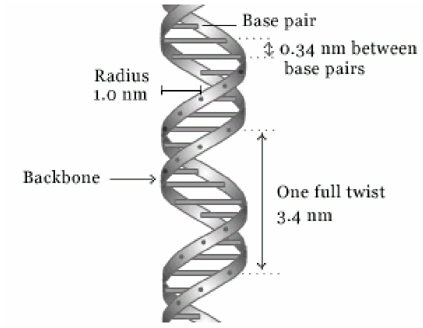


Figure 8 (continued) Interpretation of X-ray diffraction photographs. (http://www.pbs.org/wgbh/nova/photo51/;http://www.dnaftb.org/dnaftb/19/concept/index html).

At the same time, Linus Pauling, who solved the alpha-helix structure in protein, published a paper on the structure for DNA. He suggested a triple helix model (Figure 9) with the phosphates near the fibre axis and, and the bases on the outside (Pauling and Corey 1953).

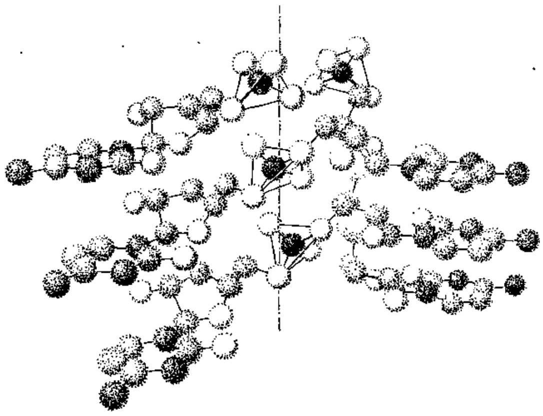


Figure 9 The triple helix mode proposed by L. Pauling

Watson and Crick indicated that this model could be right because the negative charges of the oxygen atom in each phosphate group are facing toward the middle, and stacked on top of each other. However these charges would repel one another, making it impossible for the molecule to hold together and some of the van der Waals distance appear to be too small (Watson J.D., and Crick F.H.C., 1953).

A crucial piece of information came from the Nottingham team of the British physical chemist, John M Gulland, another very important contributor. In 1947 Gulland and his co-workers published an important contribution suggesting that hydrogen bonds exist between two pairs of bases in native DNA molecules (Gulland et. al. 1947).

Watson reread their papers and postulated that nucleotides could pair and form weak bonds, hydrogen bonds which formed when nitrogen or oxygen shares a hydrogen atom (Watson 1968 p.143). However, Watson could not determine the tautomeric forms of nucleotide, enol or keto form (Figure 10). This was solved by the American crystallographer Jerry Donohue. He pointed out Watson had played with the wrong structure of guanine and thymine and strongly suggested the keto alternative again (Watson 1968 p.152).

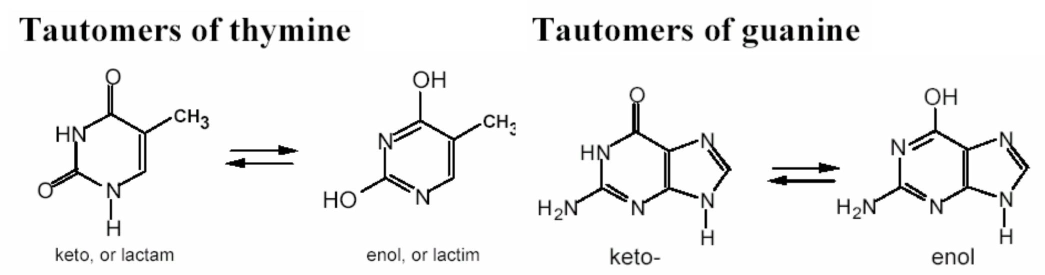


Figure 10 Tautomeric form of nucleotide.

With Donohue's correction, Watson drew the base structures on cardboard, cut them out and moved them around in pairs to see how they might fit together. He suspected that DNA had two chains and he wanted to see if the interactions between the bases might hold the structure together, like rungs in a ladder. When he played with the cardboard cutouts, it became immediately apparent that the pieces fitted together as he expected, and from this, he deduced that the interactions between the bases would involve hydrogen bonds.

Watson matched specific base pairs as below (Figure 11) and compared the width of different hydrogen-bonded pairs. This measurement is critical because each different pair (A-T or G-C) must combine to give the same distance in order to maintain an even structure which would not bulge in and out. Finally, he concluded that guanine shares three hydrogen bonds with cytosine, and adenine makes two hydrogen bonds with thymine (see Figure 11).

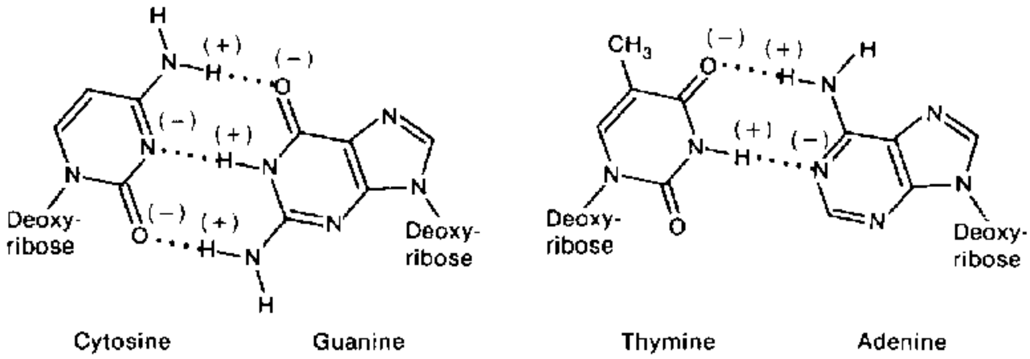


Figure 11 Hydrogen bonds (indicated by dotted lines) between purine bases (C and T on the left side of the pairs) and pyrimidine bases (G and A on the right of each pair) which form base pairs of C-G and A-T.

The base paring A-T and G-C was the key to construct DNA's double helix, and it solved one of the major problems facing the scientists who were trying to deduce its structure. After publishing their work, Crick and Watson built a three-dimensional model of DNA using brass metal shapes specified by their measurements of the base pairs (Figure 12), and the 3D model validated the structure that they had proposed in their paper, by allowing other scientists to visualise the arrangement.

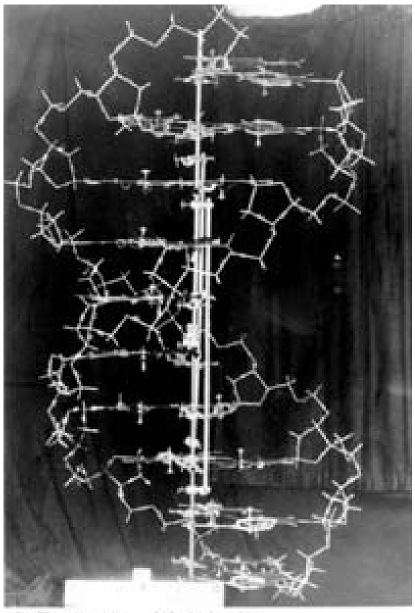


Figure 12 A stacking model of DNA and Watson and Crick's brass plate model of DNA

2.4 Conclusions - Interpretation and Visualisation in Science

It is very interesting to note that scientists make much more use of diagrams, pictures and models in communicating their ideas than might be expected. In particular, I have been fascinated by the visualisations of DNA structure, and this has been an inspirational motif in my artwork.

There is a difference in ways of interpreting in art and science. One difference is that art allows for many different interpretations which are treated as equally valid, but science does not allow for the same degree of variety in interpretation, and only some conclusions are given validity. Obviously, differences between artistic and scientific interpretation leads to different styles of visualization. Scientific visualization of the DNA structure functions as an indexical sign to explain the information, and is interpreted using analysed data. The interpreted model of DNA structure concisely represents hypotheses or theories, and the structure is comprehended by the scientific community. In contrast, artistic visualisations of DNA perform different functions: artists do not need to describe the structure as precisely as scientists might need to, because the audience has different requirements or expectations.

Richard Bright asserts that visualization plays an important role in society:

> **Humans are highly visual animals and we often think in pictures. From cave paintings to the computer, the visual image has assisted the human race in describing, classifying, ordering, analysing and ultimately reaching a greater understanding of world. Images trigger an internal response, where the viewer transforms the static image into an intellectual or an emotional experience. (Bright In: Ede 2000, p.139)**

According to Bright, a scientific visualization requires some level of knowledge in the audience to understand its interpretation. In general, the difficulty of understanding scientific knowledge is one of the reasons for the gap between science and the public. Therefore, some scientists have tried to make their visualizations of their theories or discoveries understandable to the public, in order to provide the facts about their research.

Arthur Miller pointed out that visual imagery in science is not only for communication, but it also has a value in scientific thinking and plays causal role in scientific creativity (Miller 2000, p.320 - 321). Professor Richard Woodfield shares Miller's view that visual thinking is a central characteristic of science, and that scientific discoveries frequently involve re-envisioning something in a new visual format (Kim 2004, Foreword).

As we have seen in the work of Watson and Crick earlier in the chapter, visual imagery contributed to many important steps in the discovery of DNA structure. These include X-ray diffraction photographs by Franklin, cut-out cardboard base paring by Watson, and metal models of DNA structure by Watson and Crick. Further developments in technology after 1953 have allowed scientists to visualize its structure in a variety of other ways.

Rhonda Shearer pointed out that the new scanning tunnelling microscope (STM) reveals a very different picture in which DNA structure is highly irregular and lumpy in reality. In comparison with the drawing by Odile Crick (Watson et. at. 1953), which has become a standard textbook idealization of DNA, STM images of DNA structure show the older visualisation to be an 'ideal' form (Shearer 1996). But the important thing about such ideal and diagrammatic forms is that they are easier to understand. Only when we understand at this kind of level can we appreciate the more 'realistic' forms revealed by more accurate techniques. Below, we present a selection of visualisations of DNA structure by scientists (Figure 13):

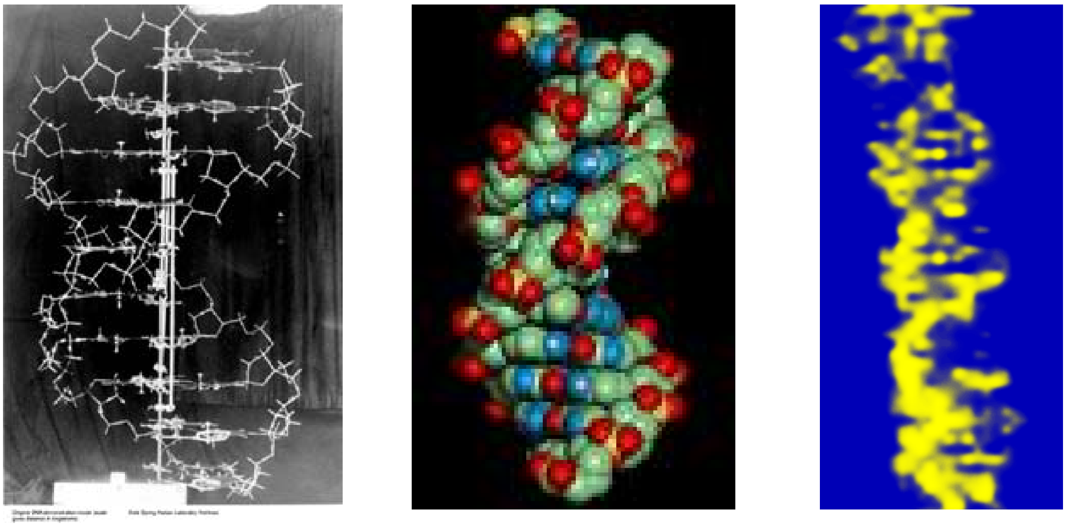


Figure 13 Different visualizations of DNA structure

Since the discovery of DNA structure, the *gene* has become one of the most popular scientific terms used both by scientists and the public, and like DNA's double helix, it has achieved the status of a cultural icon. In the following chapter, I will examine DNA as an iconic structure, and the factors that give it this status. I will analyze the role of the relationship between images and society, particularly in the interactions between art and science.

Chapter 3

DNA as Cultural Icon

3.0 Introduction

We live in a highly visual world. Visual images are found all around us, in cinema, books, television and the internet. As we say, 'seeing is believing', and 'a picture is worth a thousand words'; in other words, we cannot overestimate the power of the picture. I would like to describe the power of images, how they are important at this moment, and the relationship between images and society, by using the example of interactions between art and science.

It is easy to see that the double helix structure of DNA is everywhere: stamps, coins, films, sculptures and even music. Why is the structure so popular as an icon at this moment? Denna Jones, curator of the TwoTen Gallery and contemporary initiative at the Wellcome Trust, says it is because the double helix structure shows simplicity, symmetry and serendipity (Jones, 2003). However, this is not enough to explain why DNA is a cultural icon and such a powerful image in popular culture. This chapter explores various aspects of this question.

3.1 DNA in Science

In contemporary art, artists began depicting the double helix as a cultural icon, for example, spiralling DNA molecules are shown in Salvador Dali's paintings from the late 1950s, such as *Butterfly Landscape* (1957-8). Dali painted it because he believed that it was an important structure with significance for the future. More recently, some artists expressed their concern about the issues surrounding the science of DNA, such as cloning and transgenics, in which animals and plants are mutated into what some people regard as 'monsters' (Gamwell 2003). As Gamwell pointed out (2003), the theme of artworks inspired by DNA or genetics expressed a highly complex, ever-changing organic process rather than the pure science of DNA.

It is interesting that the double helix inspired artists before the current revolution in biology. Scientific activity in this area began to increase dramatically from 1996, when research including Dolly the sheep and the human genome project began. The graphs below illustrate the frequency of citations of Watson and Crick's paper. The Science citation index (SCI) is used as an indication of how many times particular published articles are cited in scientific journals by other researchers (Figure 14).

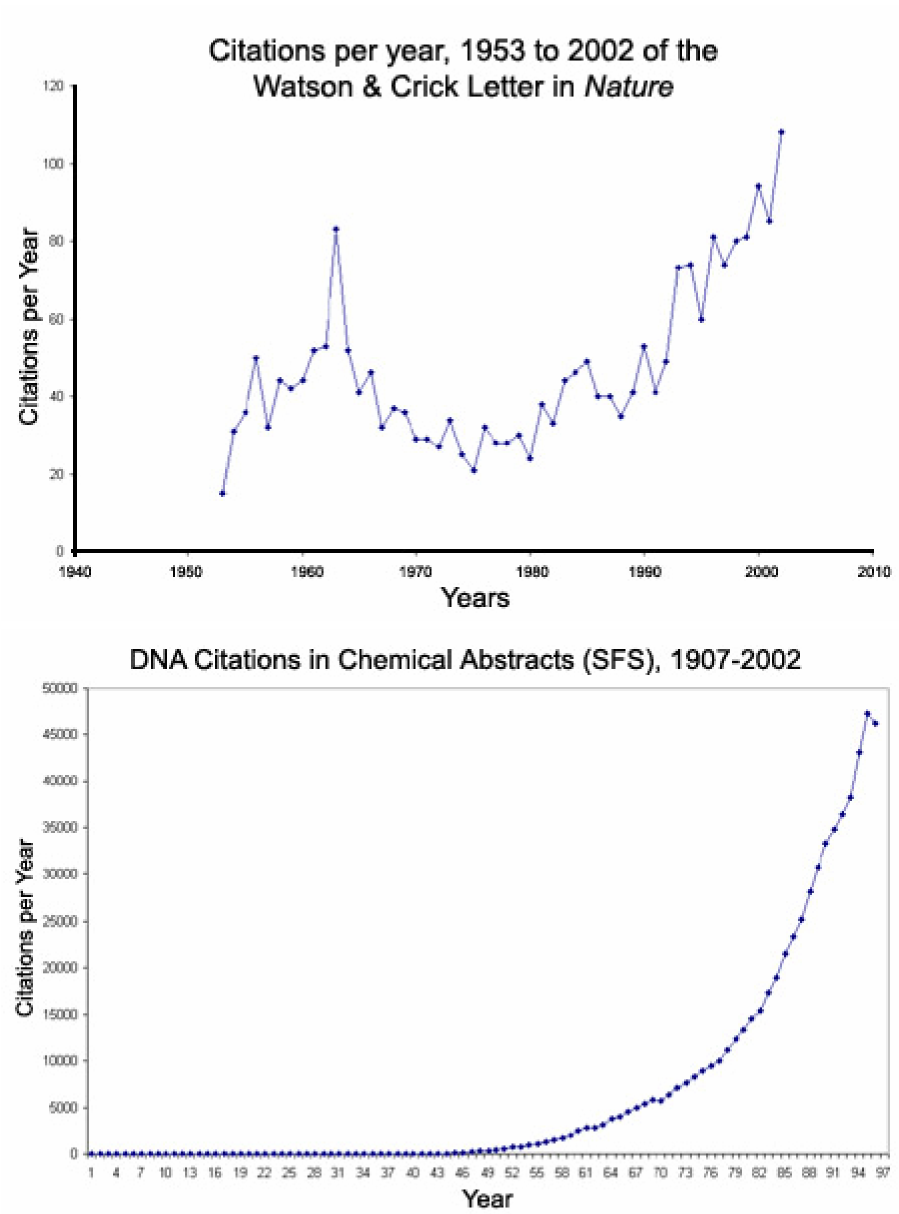


Figure 14 Numbers of citations of Watson & Crick's paper and of DNA. DNA's Double Helix: 50 years of discoveries and mysteries an exhibit of scientific achievement; http://ublib.buffalo.edu/libraries/asl/exhibits/dna/DNA50.html

In this chapter, I would like to examine why the double helix has become a cultural icon. To answer this question, it is necessary to define what an icon is. According to the Oxford English Dictionary, an icon is:

a. An image, figure, or representation; a portrait; a picture, ‘cut’, or illustration in a book; esp. applied to the ‘figures’ of animals, plants, etc. in books of Natural History.

b. An image in the solid; a monumental figure; a statue.

The word ‘icon’ is derived from the Greek, *eikon*, meaning an image, picture, sign or likeness that stands for an object by signifying or representing. Thus, we can describe a cultural icon as an object or person which is distinctive to, or particularly representative of, a specific culture. In this sense, I examined the use of DNA in Google and Amazon. On 29th March 2007, a Google search for DNA listed about 158,000,000 pages, whilst a search on Amazon shows 71,298 books and even 78 toys and games. This result suggests that DNA or gene is ubiquitous and more closely related to our life than any other scientific discoveries.

3.2 DNA as cultural icon in Art

As described in chapter 2, DNA is a biological molecule which transmits the information needed to maintain life. However, the structure of DNA or gene has also become a cultural icon. The visualisation of the double helix was a significant step because it allowed us to see the structure of an important part of what makes us human. Because of science’s aim of objectivity, the DNA model represents a supposed *truth*, but it must be borne in mind that scientific truths are often only temporary: old paradigms are replaced as new facts and ideas come into being. Previously in this chapter, I mentioned two reasons (simplicity and beauty) for the importance of DNA as a cultural icon. In addition, the visualisation of DNA provides a convenient point from which we can explore the essence of identity and the forces that shape human nature.

There are various artworks that use visualisations of chromosomes, molecules, DNA sequences, and the double helix as metaphors. Examples include

Larry Miller's *Genetic Code Certificate* (1993), Kevin Clarke's portrait of James D. Watson (1998-9), and Eduardo Kac's *Genesis* (1999). For artists, DNA or genetics is used as a way to represent their individuality, the inner essence of a person, the truth behind appearance, the nature of authentic self, and their fears of a technology that may be out of control in the future (Nelkin, 1996). For example, Eduardo Kac says:

> **'Genesis' is transgenic artwork that explores the intricate relationship between biology, belief systems, information technology, dialogical interaction, ethics and the Internet (Travis 2000).**

3.3 Genetics in popular culture

In the 20th century, *gene* is a more popular scientific term than any other, and the images or visual metaphors of the double helix achieve the status of cultural icons. Beyond the role of the gene in heredity as genetic material, the pictorial forms of genes such as a double helix and the twenty-three pairs of chromosomes in humans have represented "life itself" or the "secret of life".

Biotechnology based on the science of DNA can be easily found in novels, films and TV programs. Most of them depict warnings of the advent of fictional chimeras (e.g. Frankenstein's monster), and the potential harm of genetic engineering or cloning. The representation of genes, genetics or biotechnology in films or novels depicts them as essential factors that determine everything, even human destiny. As noted above, DNA has become synonymous with genes, genetics, or genetic engineering in popular culture, has gained iconic significance, and has thus become a metaphor for the very essence of a human being. Therefore, the representations of DNA have different symbolic values and are represented in different ways which are independent of its biological meaning. The representation of DNA in films is summarised in Table 1 below:

Title	Year	Remark
GATTACA	1997	Explores a design-conscious world in which "designer" babies are the norm and only the genetically well-endowed get to the top.
Multiplicity	1996	Michael Keaton is a working man who clones himself again and again in order to have time to fulfil all his work and personal responsibilities.
The Island of Dr. Moreau	1996	This film was adapted from the 1896 H.G. Wells story of an isolated scientist and his genetically altered beast-people.
Godsend	1993	After their young son is killed in a freak accident, a couple approach a scientist (Robert De Niro) about bringing him back to life through an experimental (and illegal) cloning process.
Jurassic Park	1997	Michael Crichton's story about an amusement park featuring full-sized, living dinosaurs reconstructed from petrified DNA.
Swamp Thing	1982	A well-meaning researcher wants to combine plant and animal genes in order to give plants "aggressive" qualities that will help him feed the world.
The Island	2005	Human cloning for transplantation to replace their contaminated organ.
Minority Report	2002	A trio of genetically modified "pre-cogs" warn of murders before they happen. Based on a novelette by Phillip K. Dick.
Equilibrium	2002	In the monochromatic and sedated society, artifacts from the old world are destroyed and the population is required to take sedatives by Kurt Wimmer.
She Devil	1951	A scientist tries to mix the genes of humans and insects to cure disease.
Blade Runner	1982	Human clones are used for slave labour. Based on the book *Do Androids Dream of Electric Sheep?* by Phillip K. Dick.
Total Recall	1990	Theme of cloning. Based on a novelette by Dick.

Table 1 Films with reference to DNA and/or genetics.

The number of references to DNA in popular culture proves that DNA structure has become a symbol of science and technology, particularly biotechnology. Richard Dawkins, the biologist and evolutionary theorist, in his book *Selfish Gene*, created the new concept of the ‘meme’:

The new soup is the soup of human culture. We need a name for the new replicator, a noun which conveys the idea of a unit of cultural transmission, or a unit of *imitation*. 'Mimeme' comes from a suitable Greek root, but I want a monosyllable that sounds a bit like 'gene'. I hope my classicist friends will forgive me if I abbreviate mimeme to *meme*... (Dawkins 1989 p. 206)

Dawkins stressed that not only *genes* are transferred, but also that our *ideas* transfer and contribute to cultural evolution in our society. In this sense, in my view, the concept that DNA can shape our future can also be called a *meme*. Dawkins pointed out that there are many functions of DNA, such as transcription, mutation, repair, replication and recombination. The meme, the unit of information or cultural transmission, also has many functions in our society, as does DNA in a living cell. With the development of technology, the rate of information movement is increasing in our culture and our society, so memes are transferred increasingly quickly also.

Images of DNA, genes, and genetics are found in stamps (Figure 15). In fact, most countries issuing these kinds of things intend to commemorate scientists or the scientific achievements. Biotechnology or scientific discoveries on stamps can be found across the world, and they provide an opportunity to participate in the enquiries of the biosciences and culture, and the stamp serves to educate people to be aware of these issues.

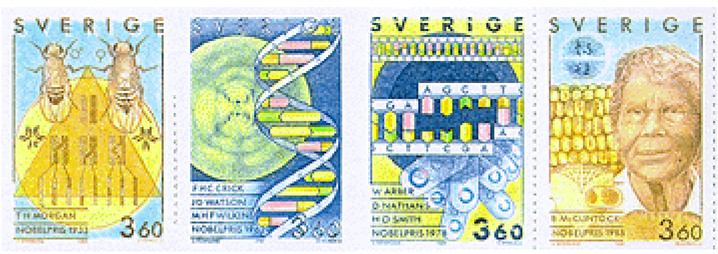


Figure 15 Stamps engraved by Martin Mörck after originals by Göran Österlund.

These 'Nobel Stamps' of 1989 by Sweden Postal Stamps constitute an artistic, cultural and scientific heritage of humanity. The stamps represented discoveries related to DNA: fruit flies that are used in experiments by Thomas H.

Morgan; the double helix of James Watson and Francis Crick; DNA digested by restriction enzymes in experiments by Werner et al; and lastly the discovery by Barbara McClintock of how genes sometimes change places, also known as 'jumping genes'.

Moreover, the double helix is shown in toys, games and commercial advertisements. The shape of DNA can be found even in children's playground equipment, souvenirs such as T-shirts, bracelets and coffee mugs.

3.4 'Iconic DNA' and genetic determinism

The science of genetics is increasingly becoming part of our lives. Various medical diagnostic tests or therapies use methods based on DNA technology. This technology is also used in the preservation of foods, to make crops resistant to harmful insects, and in forensic science in genetic fingerprinting. These advances lead people to be aware of the enormous potential of biotechnology and social issues related to it. And also the debates about the issue are mostly based on a paradigm of reductionism that postulates that all attributes, characters, and forms of lives are determined by genes. Thus, the views about bioscience and biotechnology challenge our fundamental concepts about life, nature, nurture, humanity and society.

In this section, I would like to discuss the social responses to genetics. No discussion of genetics and society would be complete without mentioning eugenics, the application of genetic knowledge to reduce the number of the population who carry defective genetic traits. In the view of genetic determinists, genetic tests and gene therapy can reduce all of the suffering caused by genetic disorders. In fact, the potential to cure disease increased after the completion of the Human Genome Project (HGP) and advanced cloning technology.

Historically, the term "eugenics" (literally, "good genes") was coined in 1883 by Francis Galton to describe selective breeding based on genetic merit. After Galton, successors with similar views appropriated Darwin's theory of natural selection to support their ideas: Herbert Spencer, who was an English philosopher and political theorist in 19th century, described it as "survival of the fittest". The ideas of eugenics spread to America in the1900's and passed back to Europe in 1930's. During this time, sterilization law was passed in Hitler's Germany, and those who were genetically inferior with disease and even unwed mothers, prostitutes, petty criminals, alcoholics, homosexuals, and the mentally ill had to undergo sterilization. In addition, limits on immigration from Eastern and Southern Europe were applied in America on eugenic grounds. In practice, the methods of genetic testing, gene therapy, genetic engineering and other DNA-combined technologies are used. Today these kinds of medical applications based on genetics are largely acceptable and offer health benefits to individuals.

Because of the potential horrors associated with genetics, people are still concerned about gene science, despite the apparent good intentions of the scientists, and the potential benefits of gene technology. These concerns can be seen in popular culture such as films and novels, for example. The film "Gattaca" depicts a future society in which genetically-enhanced babies can be produced by parents who can afford it, and warns us of a society discriminated by genes and wealth. This fiction could actually be realized in the near future through the successful cloning of mammals using somatic nuclear transfer. Dolly the sheep, the first cloned mammal, is not only a scientific milestone but also raises social, ethnical, and economic issues. The public response to cloning reflects the futuristic fantasies and Frankenstein fears; both responses always come with new scientific discoveries, and especially with biotechnology (Nelkin and Lindee, 1998).

Modern genetics attempts to avoid the negative associations with eugenics, as carried out in Nazi Germany for example, and instead tries to promote more creative uses for this technology. Nelkin and Lindee called this approach "genetic essentialism" in their book, *The DNA Mystique: The Gene as a Cultural Icon.* (Nelkin and Lindee 1995, p. 149). They pointed out those scientists who involved with genetics, for example James Watson claims about powers of DNA to suggestions for eugenic and genetic determination.

3.5 Conclusions - The Power of DNA in Culture

In *The DNA Mystique*, Nelkin and Lindee analysed representations of DNA in popular culture, and ultimately regard DNA as a cultural icon. As they explain, DNA has become a metaphor to represent where we are from, who we are now, and who we will be. It is a key to understanding identity and individuality through DNA-sequencing. Beyond the biological characteristics of DNA, it can be further applied to explain social differences and the relationship between human beings and their culture. The power of DNA as an explanatory concept has led to widespread beliefs such as genetic determinism and essentialism. These powerful beliefs have contributed to the status of DNA as a cultural icon. After the birth of Dolly the sheep, the icon of DNA has gone from the scientific domain and touched the religious domain: geneticists have been accused of “playing God”, which means that they create and control organisms through scientific achievement in ways which were previously explained by religious beliefs.

Let us go back to the question of why DNA has become a cultural icon today. Firstly, we can think of the aesthetic viewpoints. The double helix is very simple and beautiful to depict; we see its spiral structure frequently in our culture, for instance, in pillars in architecture. Secondly, it is a key to open a door, a so-called “secret of life”. To understand what is life is our ceaseless desire as human beings. It leads us to question and determine the origin of all living organisms including humans, and to explain identity or individuality in a way that does not simply reflect biological information but also our status in society in the past, present, and future.

As science and technology are both regarded as important factors that shape our culture, they have the power to influence as religion once did in the middle-ages. Taking account of the economic aspects of the globalized and capitalist world, the importance of DNA can not be overlooked; it can and has been applied to agriculture, bio-industry and medicine. Thus we can see that DNA is combined with these various factors to become an icon in our culture.

So-called ‘genetic determinists’ or essentialists believe that nurture such as social environment is less important than our genetic nature. I believe that nature and nurture are equally important to our cultural identity, and that these two elements that shape our identities are like the two backbones of DNA’s double helix. So, with this visual metaphor, Sci-Art is similar to the base-pair connections between the two strands. In this way, Sci-Art bridges the gap between nature and nurture, between scientific knowledge and artistic culture.

The next chapter will examine the visualization of DNA by scientists, and how drawing reflects their research interests. I will discuss how the visualisation can facilitate the effective communication of information by improving ways of understanding various things.

Chapter 4

Visualisation of DNA by scientists

4.0 Introduction

Fifty years ago, Watson and Crick revealed the structure of DNA. Now, in the century of the genome, the double helix structure of DNA has become an art and design icon. If one searches the internet, there are numerous products such as coins, stamps, and neckties, as well as sculptures, paintings and pictures of DNA's double-helix shape.

The previous chapter examined why the double helix is so popular and has become an icon in this century. The reason is that the structure has simple symmetrical characteristics that are making it attractive to people. It is also that it represents a symbol of what we are as opposed to why we are. For example, the simplicity of structures like spiral forms are used as metaphors and are easily depicted. This type of icon or image of DNA is produced by a process of information visualisation.

Visualisation can facilitate the effective communication of information by improving ways of understanding various things. Given these functions of visualisation, it appears likely to us that there is little difference between scientific visualisation and art's visualisation. Unfortunately, relatively little research has been carried out on scientific visualisation and how it is related to scientists' research. Therefore, we need to distinguish scientific visualisation from other types of information visualisation.

Before delving into my analysis of scientific visualisation and its processes, it is worth taking a quick look at the definitions of scientific visualisation and information visualisation. Scientific and information visualisation can be classified according to the data they depend on. Scientific visualisation is based on physical and/or chemical data, like atoms, molecules, DNA or other, whilst information visualisation is based on abstract data (Card et al, 1999).

This chapter will look at some examples of scientific visualisation to elucidate how this type of visualisation is different from that of the artist. To celebrate the discovery of DNA structure in 1953, there was a conference at Cold Harbour Spring Laboratory (CSHL) in the USA, The Biology of DNA, 28 February 2003, where 40 of the most prominent biologists in the world were asked by Peter Sherwood to draw their concept of what DNA means to them. Especially interesting from my point of view is that their drawings are related to their research work.

It may be useful to start by examining separately how scientists visualise their work, what informs the illustrations of the researchers themselves, and what are the problems in depicting their results. We can divide the process of visualisation into two categories: direct visual observation and indirect observation. Direct observation includes information gathered with the eye, e.g. through a microscope; indirect observation is the collection of data using non-visual-based technology, e.g. gene sequencing and X-ray crystallography, as used in the scientific studies of DNA.

4.1 Direct Observation

Let us examine in the first instance a drawing by Dr. Tatusya Hirano of chromosome structure from the CSHL conference (Figure 16).

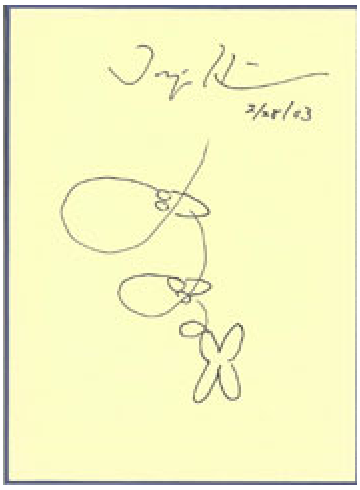


Figure 16 Dr.T Hirano's concept of DNA. He draws chromosome to express his conception of DNA. (http://www.nature.com/nature/dna50/gallery/images/img_hirano.jpg).

Why did Dr. Hirano draw the DNA like this, and which of his experiences impacted on the drawing? If we look at some of Dr Hirano's research, we find visualisations of chromosomes as seen in Figure 17 (Ono et al 2003). The images are made using a combination of microscopy, photography and fluorescent technology. Figure 17 gives one clue as to why he draws the concept of DNA like the butterfly form seen in Figure 16. Something similar may be observed in connection with his research interest in understanding the molecular mechanisms responsible for chromosome assembly and segregation during mitosis: the drawing is symbolically relevant to his research.

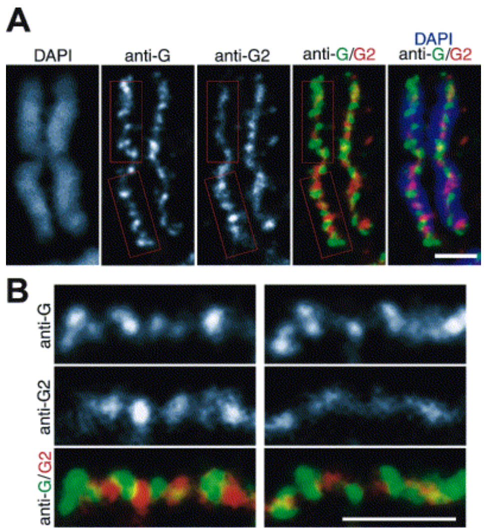


Figure 17 Differential Localization of Condensin I and Condensin II on HeLa Chromosomes. Takao Ono et.al., *Cell* 115(1):109-121 (2003). Dr. T Hirano and his colleagues present mitotic chromosome architecture in vertebrate cells using immunofluorescence microscope.

With regard to his research work and images, another example is shown below (Figure 18).

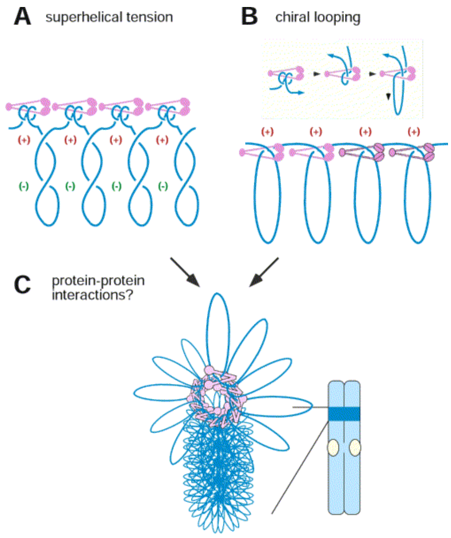


Figure 18 Hypothetical Models for the Contribution of Condensin to Chromosome Organization. Jason R. Swelldow and Tastsuya Hirano, the making of the mitotic chromosome modern insight into classical questions, *Cell* 11(3) 557-569 (2003).

This figure also shows how this type of visualisation can help scientists to understand their results: simplified figures like Figure 18 are frequently found in review papers (Swelldow and Hirano 2003). That is, the figures promote understanding of the research results and facilitate communication between scientists.

Experimental results can be interpreted in various ways. The strongest evidence is direct-pictures using microscopes, but unfortunately, not all experimental results can be seen through a microscope. Scientists have to interpret the data, explain what they have done, and what the results mean. In the following section, I will develop a view based on visualisation and interpretation of data obtained by indirect observation methods that have been used to help discover the character of molecules.

4.2 Indirect Observation

Dr. Tania Baker who researched DNA transposition at the Massachusetts Institute of Technology drew the concept of DNA from the CSHL conference (Figure 19). It is difficult to imagine her concept of DNA (Figure 19) from the experimental results in Figure 20 but there is a connection between Figure 19 and Figure 21 (Burton and Baker 2003).

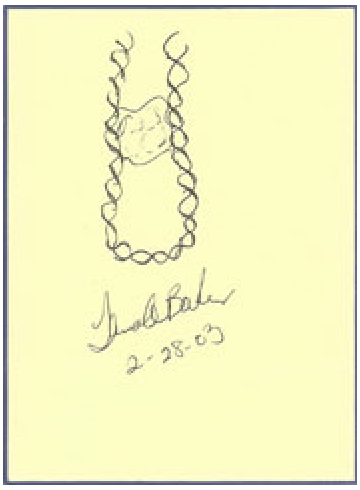


Figure 19 A concept of DNA by Dr. Tania Baker who research DNA transposition at the Massachusetts Institute of Technology.

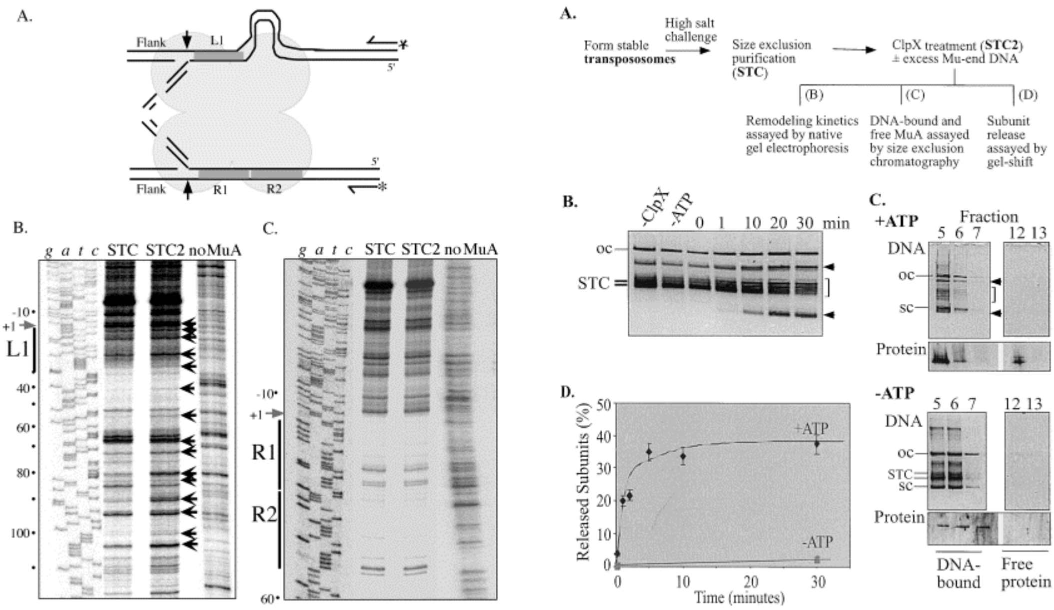


Figure 20 Scheme of the methods used to analyse the interaction DNA and protein (transposon), and results by gel eletrophoresis assay and DNA-ase fingerprinting assay. These figures show which data is used to interpret and understand molecular interaction. Brianna M. Burton and Tania A. Baker, Mu transposome architecture ensures that unfolding by ClpX or proteolysis by ClpXP remodels but does not destroy the complex, *Chemistry and Biology* 10(5): 453-472(2003).

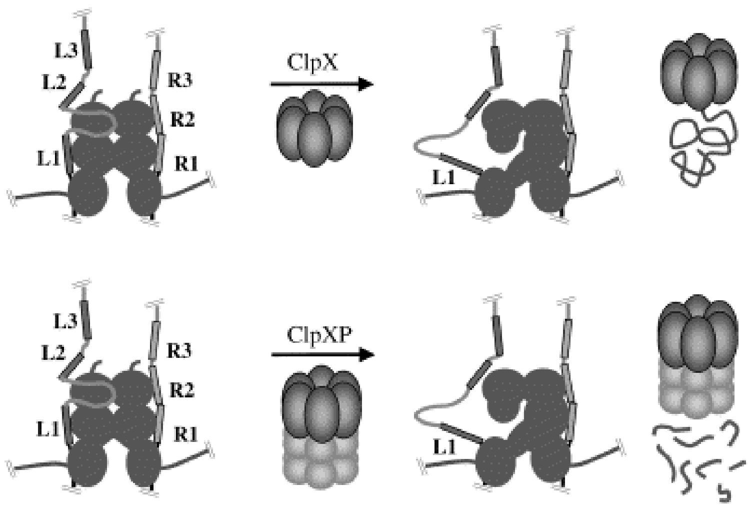


Figure 21 Model for transposome remodelling tow products result from ClpX-mediated, Brianna M. Burton and Tania A. Baker, Chemistry and Biology 10(5): 453-472(2003).

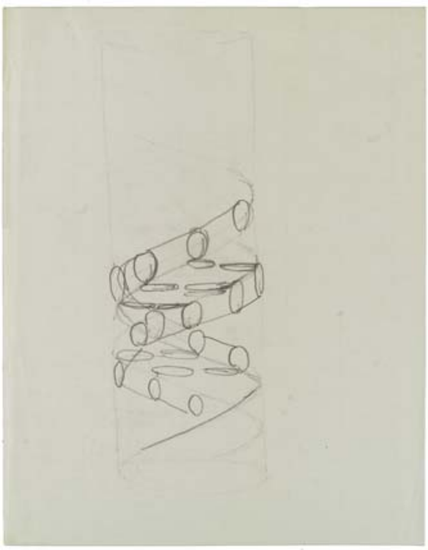
Figure 21 shows diagrams built on results of many experiments, including techniques listed in Figure 22. The drawing can be seen as very a useful tool for scientists to understand molecular mechanisms. This kind of visualisation, based on indirect observation, is different from images based on direct observation, because the former requires interpretation in ways that the latter does not.

As mentioned previously, the relevance of the connection between research interests and drawings of DNA concepts is also found in Dr Tania A. Baker's case. Her research is focused on understanding the mechanism and regulation of two classes of marcromolecular machine: the Clp/Hsp100 family of protein unfolding enzyme and the proteins that catalyse DNA transposition. That is why she drew the indeterminate shape (actually representing a protein) between the two helices. I think she might have wanted to visualise the protein transposome that interacts with DNA in her drawing, because that was her concept of DNA.

4.3 Information in visualisation

In this section I draw attention to scientific discovery as an important source of information about visualisation. One purpose of scientists' visualization is to generate, communicate and disseminate new knowledge through publication. They show diagrams and figures in order for others to understand their accomplishments more easily. Visualisation is an integral part of the way in which scientists express their conceptual images of their research. Images can be simplified and shown in papers, but the processing of images is not simple; it involves very sophisticated mental manipulation. Diagrams, figures and sketches are crucial aids used to interpret and understand scientific research, which could also make them popular as icons in wider society. The importance of visualisation is related to the way it transmits information, and this depends on how the experimental results are developed and how their visualisation is organised and matched with their verbal representation.

Scientific visualisation is typically taken as depictions of an actual or possible state of nature. In these terms, scientists share nature with artists, even though they interpret the same things differently. How do scientists respond to features that have never been seen before? And how do they want to describe these things? I would like to discuss the response and processing of scientific visualisation, through which we can deduce or interpret their intentions. Let us consider examples from laboratory notebooks and letters of scientists who contributed to the discovery of DNA structure.



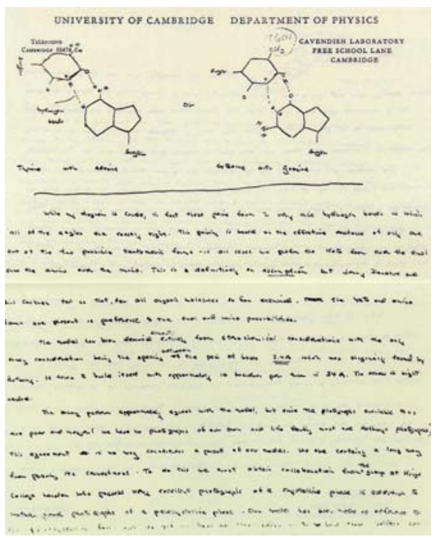

UNIVERSITY OF CAMBRIDGE DEPARTMENT OF PHYSICS
CAVENDISH LABORATORY
FREE SCHOOL LANE
CAMBRIDGE

Figure 22a Drawing of double helix by Crick from http://profiles.nlm.nih.gov /SC/B/B/W/B/.
22b Correspondence of James Watson to Max Delbruck (March 12, 1953) from http://osulibrary.oregonstate.edu/specialcollections/coll/pauling/dna/corr/ watson03-pg02-xl.htm

As can be seen in Figure 22a above, the drawing by Crick is very similar to the diagram in the famous paper published in *Nature*. Before describing the process of scientific visualisation, I will briefly discuss how Watson and Crick drew the double helix. They conducted no DNA experiments of their own, instead they interpreted the previous experimental results of others, and unified these disparate findings into a coherent theory, finally producing a diagram of a double helix. They had different backgrounds that are complementary: Crick studied physics and X-ray crystallography whilst Watson studied genetics.

Returning to how scientific visualisation works. At first Crick and Watson described the DNA molecule directly with words. To do this, they needed to observe the features of DNA. Watson was focusing on the suggestiveness of X-ray diffraction patterns for a structural model of the DNA molecule. It contrasts to the approach of Rosalind Franklin and Maurice Wilkins who analysed crystal structures that are used for the phase effects of the scattering of X-rays (Figure 23a). Franklin and Wilkins postulated a helix structure, but it is not easy to construct a logical ordered helix structure. In order to determine the structure, they used a table that showed that the amount of DNA and its four types of base varied widely from species to species, but that the ratios of A:T and C:G were approximately 1:1.

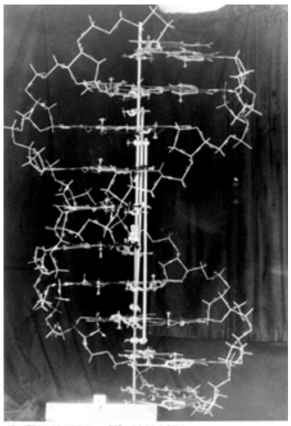
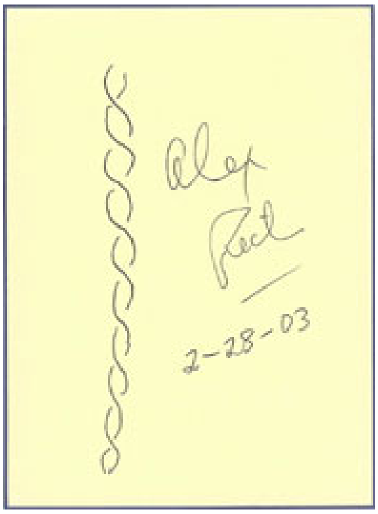


Figure 23a Rosalind Franklin's X-ray diffraction photo of structure B from http://osulibrary.oregonstate.edu/specialcollections/coll/pauling/dna/pictures /fran klin-typeBphoto.html. **23b** Original demonstration DNA structure model by Watson and Crick from http://osulibrary.oregonstate.edu/specialcollections/coll/pauling/dna/pictu res/ dna-model.html

However, Watson drew the binding of A and T, and G and C as shown in Figure 22b to make a constant distance between them. Finally he could determine the double helix DNA structure and then Crick tried to draw the structure based on their findings; he depicted the double helix. Scientists want to identify and create some important features and represent scientific facts successfully. The structure in Figure 23b is the original demonstration model of DNA in 3D produced by Watson and Crick.



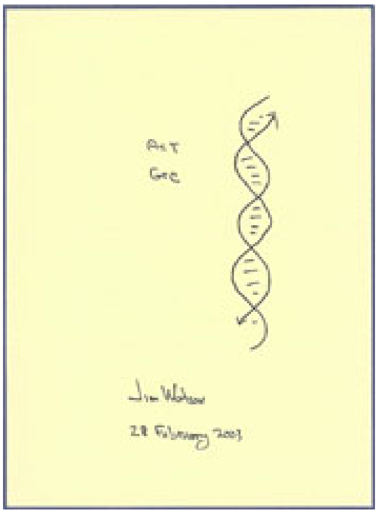


Figure 24a Left-handed Z DNA by Alex Rich. **25b** right-handed B DNA by Watson from http://www.nature.com/nature/dna50/gallery/index.html

It is important to look at how visualisation may reflect, and even limit research and thinking. Figure 24 shows clearly the link between scientific visualisation and research interest by scientists, even though these drawings were not intended to provide scientific information. Alex Rich drew a left-handed double helix (Figure 24a) because he discovered left-handed DNA, whilst Watson depicted a right-handed double helix, using arrows that show clearly the direction (Figure 24b).

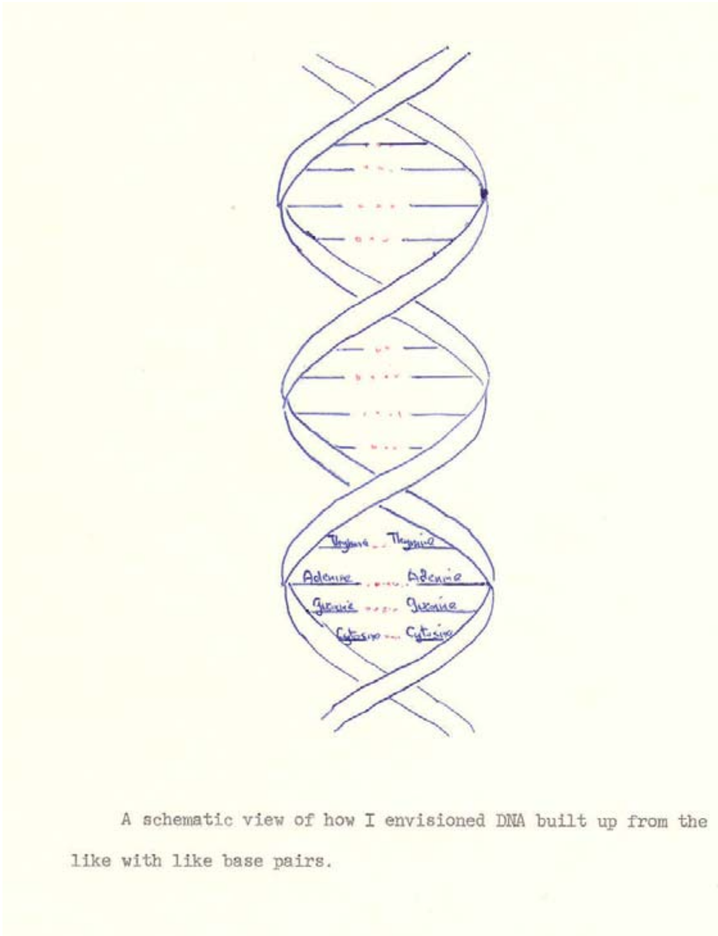


Figure 25 Drawing of DNA structure by Watson from http://library.cshl.edu /archives/archives/Watson%20 Arc hives/dnadrawing.htm

Looking at another drawing by Watson (Figure 25), he described the structure with red dots and words that give pieces of information about how the double helix is built up. Two red dots indicate a hydrogen bond between A and T, whilst three red dots represent a bond between G and C. This is a typical drawing from which we can understand that scientists intend to carry information and communicate with other people.

We have looked at examples of visualisation from several different sources. The examples highlight important points about scientific visualisation. Firstly, all visual representation expresses a particular method of interest of the creator. Secondly, it should be clear that the images and results of interpretation are based on implicit knowledge used by scientists.

As I mentioned previously, scientists depict their observation directly using instruments such as microscopes or indirectly using verbal communication based on results such as statistics tables or chemical and physical formulas.

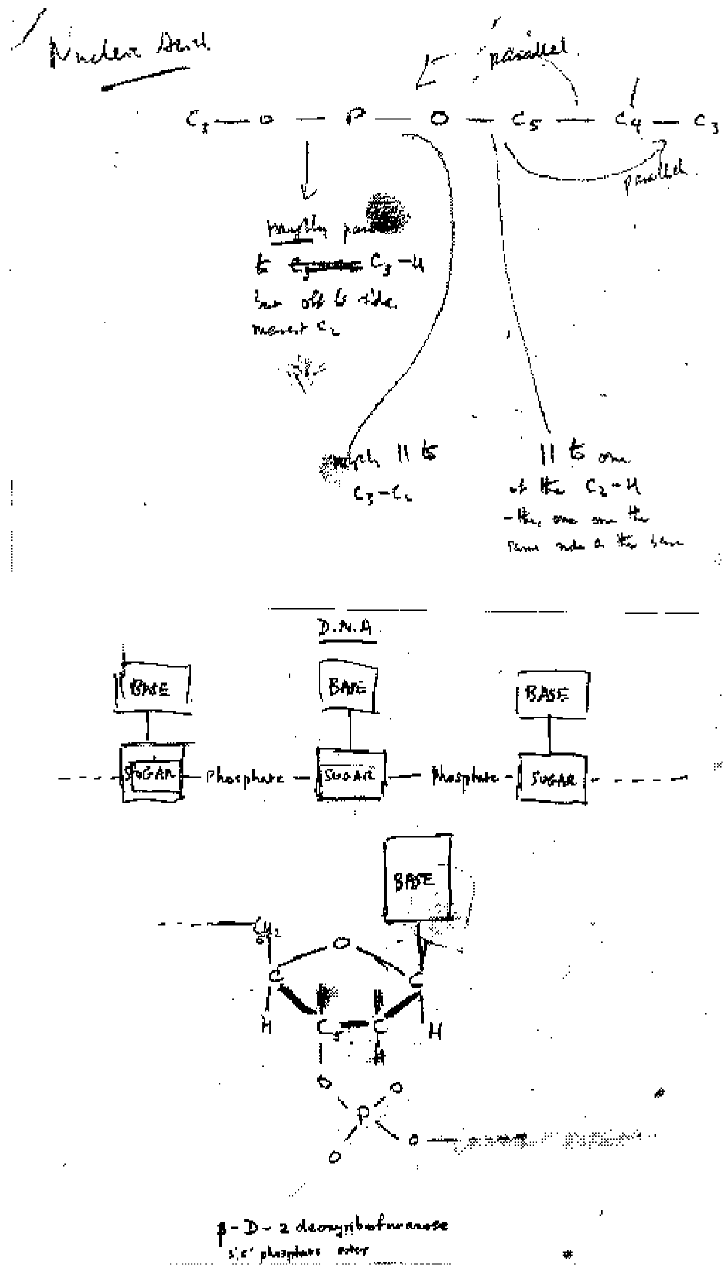


Figure 26a Note on the possible configuration of bases in DNA structure by Crick (http://profiles.nlm.nih.gov/SC/B/B/V/Z/_/scbbvz.pdf). **27b** Note on the structure of DNA by Crick (http://profiles.nlm.nih.gov/SC/B/B/W/C/_/scbbwc.pdf).

Figure 26 shows an interpretation of raw data based on scientific knowledge by Crick. At first he drew the bases in the linear form and used chemical configuration and bonds between molecules. Then he described DNA structure with a very simple diagram.

The processing from Crick's idea to diagram; the type of processing can be called 2-Dimensional patterning through interpretation. Card, in his book *Information visualisation using vision to think* (1999), categorised information visualisation into four stages. The first stage is 1-Dimensional description consisting of writing down their mental activities in verbal expression (reconstruction of knowledge).

The second stage is 2-Dimensional patterning through interpretation. These types of processing, 1-D description and 2-D patterning are repeated until they complete a visual representation. This repeating can also make mental images and words merge, and create proto-presentations through the interaction of imagination and knowledge.

The third stage of processing is 3-Dimensional structuring that shows more closely and clearly the truths in nature. As can be seen in the original demonstration DNA structure model (Figure 24b), the model shows the exact location of molecules such as bases, sugars, and the phosphate 'backbone'. Admittedly, this model is not perfect, but we can visualise how each molecule is ordered based on accumulated knowledge and interpretation. Thus we can call this type of processing the structuring of knowledge.

Finally, the fourth stage involves 4-dimensional processing to enhance understanding. Scientists want to generate and disseminate new knowledge that is published with various tables, diagrams, figures and words. To do this, they need effective tools of visualisation. I think the above mentioned figures (scientists' drawing at CHSL) are good examples from which we can deduce and interpret their intention.

4.5 Conclusions

From what we have seen of the drawings and explanations of the concept of DNA, it should not surprise us to discover the relationship between imagination and human beings. As mentioned above, scientists have used figures to understand and communicate with themselves and with the public. Their drawing is a reflection of their concept of DNA and their research. I think it is a kind of scientific *imagination*. Imagination is a kind of psychical power that can describe or visualise some things which have no visible form.

Scientific imagination cannot produce any meaningful product without knowledge; that is why I mentioned research interests in relation to the scientists' drawings. Those drawings are a product of the concept of DNA based on their research results or interests. When humans want to know the truth of nature, they make an effort to imagine what the truth is. When scientists want to know about natural phenomena, they imagine mechanisms, shapes, interactions – they try to describe with imagination things which can be drawings or not. They need an accumulation and recombination of knowledge, interpretation, and understanding discoveries by themselves and others.

In the next chapter I will examine artists' visualization of DNA as their subject. The visualisation of DNA by artists is more conceptual. Artists have interpreted DNA as themes of personal identity, monsters, transgenics, eugenics, and commodity.

Chapter 5

Visualisation of DNA by artists

5.0 DNA as an artist's subject

As discussed in Chapter 4, scientific visualization is used to understand and communicate with other scientists and the public. This is regarded as a very useful way to show what they have found and what they postulate. The drawings made at the Cold Spring Harbour Laboratory about the concept of DNA reflected the interest areas of the researchers, and they used imagination to express their results and thoughts.

In this chapter I would like to explain artists' visualization of DNA as their subject. A number of artists use scientific findings and abstract theories, and this raises some questions: why do artists visualise scientific discoveries or natural phenomena? How do artists interpret these in their artworks? And with regard to these aspects, what is the role of Sci-Art in present and future society?

Genetics, biotechnology and life sciences are scientific areas related to DNA which are regarded as important research topics. They provide fertile ground for both scientific research and artistic production, but which are seen from different perspectives by each group. Philip R. Reilly explained very clearly about the different views of DNA from scientific and artistic viewpoints, as he comments below:

> **Scientists try to solve the mysteries of DNA; artists contemplate them. (Anker and Nelkin 2004)**

To solve the mysteries of nature, scientists use given information, develop theories, and finally prove them. These kinds of scientific activities consequently give the public more chances to understand the nature of where of we live and what we are, whilst art allows us to contemplate and consider the effect of scientific discoveries on the world.

5.1 First DNA structure in painting

When Crick and Watson discovered the structure of DNA in 1953, it was a big issue for scientists, but not for artists. At that time, DNA was no more than a biochemical structure for artists who hardly thought it could be an art subject.

Before moving on to DNA as an artistic subject, I will briefly describe a movement of art in mid-20th century. From 1940 until 1955 in the western art world, abstract expressionism was popular and searched for answers to the questions of human existence. Abstract expressionists such as Jackson Pollock created action painting and Mark Rothko created colour field paintings, believing that painting was considered as a pure expression of emotion and means of visual communication.

The first art work using DNA was created 4 years after Watson and Crick published their discovery of DNA: Salvador Dali painted the structure of DNA in his painting of 1957-8 called *Butterfly Landscape (The Great Masturbator in a Surrealist Landscape with D.N.A.).* He believed that science would soon be able to fully explain the nature of reality. After scientists discovered the double helix, Dali thought that the spiral was an important key and could prove the very basis of life. He was always interested in science and religion in his life (Kemp 2003).

5.2 Visualization of DNA by artists

According to Martin Kemp, professor of art history at Oxford University, U.K.:

> **No molecule in the history of science has reached the iconic status of the double helix of DNA. Its image has been imprinted on all aspects of society from science, art, music, cinema, architecture and advertising (Kemp 2003).**

Kemp explained that scientists explore and develop a greater understanding of the natural world by creating visual representations. In particular, he emphasised that the double helix has become a cultural icon in the 21st century. There are many artists who have used DNA as their subject of work since Dali, therefore there are many different ways of visualizing DNA used by artists. They touched on the social and cultural implications of genetic research through science which has formed the movement of sci-art in contemporary art. How do artists visualize and interpret DNA in this context?

I would like to organize this chapter into five sections by artists' subjects; new portrait, monsters, transgenic, eugenics, and commodity. These five sections are based on a book *The Molecular Gaze: Art In The Genetic Age* (Anker and Nelkin 2004). It will explain how artists employ DNA and the various ways in which they visualise it in their work. I will discuss the reflection of scientific finding, focusing on DNA and genetics, and on art in our culture.

5.2.1 DNA as the new portrait

There have been many artists who have defined the body as DNA code information such as "A, T, G, C" since the human genome project started and its potential function affected our society. For example, Kevin Clarke and Marc Quinn's genetic portraits, Dennis Ashbaugh's autoradiograph and Inigo Manglano-Ovalle's DNA portraits. Their works can be seen as revealing the personal identity and the invisible essence of their subjects.

Kevin Clarke made a first abstract *Portrait of John Cage* (who was a famous composer and artist) in 1992 and *Portrait of James D Watson* (the co-discoverer of DNA structure) in 1998-1999, and then later he made many portraits of artists and scientists using their DNA. Clarke explored new ways of depicting people as a portrait photographer by genetic code, ATGC, which can be used to identify individuals. Clarke asked scientists to isolate people's DNA and to sequence the bases A, T, G, and C. He combined these alphabets with some ready made objects in order to imply the subject's identity which is the essential and intrinsic characteristic of humankind. (Travis 2000)

In 2001, Marc Quinn created *A Portrait of Sir John Sulston* (a Nobel laureate in physiology) in 2002, which is now on permanent exhibition at the National Portrait Gallery in London. It is the first genomic portrait, amongst all the other realistic figurative portraits in the gallery. Quinn's portrait is not the traditional way in which people identify with their faces or appearances. A technique used in the portrait, inserting Sulston's DNA derived from sperm into a vector and transforming into *E. coli* bacteria, a method which was first used to discover genome sequences in early genomics. Finally, it ends up as patterns of migrating cells positioned in the centre and a big square mirror-like frame which reflects the viewer's image (National Portrait Gallery e-newsletter 2001).

Dennis Ashbaugh explored a new concept of portraiture using DNA sequencing documented by digital imaging as a basis for large scale paintings. In 1992, he painted *Designer Gene* by autoradiograph which provided a means for visualizing the invisible. The autoradiograph was developed to determine the size of DNA sequences using plutonium 32, a radioactive isotope normally used to identify characteristics of a specific molecule in molecular biology. His genetic portraits combine and explore traditional abstract painting with scientific technology (Rose 2006).

Inigo Manglano-Ovalle made 48 DNA portraits in a series called *Garden of Delights* of large images based on genetic fingerprints of his sisters in 1998. Traditional fingerprints are used to identify individuals in forensic science, and now DNA fingerprinting is used in molecular biology to identify specific DNA sequences of individuals. In this process, DNA is 'amplified' with specific restriction enzymes to show unique patterns, so it can be used to identify a person (Pollack 2000).

The artists mentioned above have changed or reinvented the concept of the portrait from an 'objective' visual likeness to an abstract representation by using DNA technology. As scientists used DNA sequences to identify and characterise specific genes or to compare them for their research, artists have used genetics from a similar perspective of DNA as the essence of identity. It is not a new concept for an artist to attempt to describe identity; the pursuit of identity is a recurrent theme in artistic works. The application of DNA science and technology, such as DNA fingerprinting or foot printing to reveal identity, might have inspired some artists who have been trying to find new approaches to express their concept of human identity. Admittedly, to identify individuals, photographs have been used, and have replaced portraits using drawing or painting which were the first of extrinsic personal identification. At this point in time photography is being replaced by DNA to identify individuals in our cultural life.

There is an argument that portraits using DNA could be too narrowly interpreted even though the portraits have revealed the inner domain of a person behind the surface appearance. Some people still believe that the portraits should show literal appearances such as human faces and shapes. One pioneer in the field of medical anthropology, Margaret Lock, argues that many artists who make artworks with genetic subjects are less concerned with social culture than the creation of their own symbolic forms, which are simplified in DNA code (Lock 2002 p. 299-377)**.** Lock also points out that complex cultural factors affect perceptions of health and illness as well as the critical relationship between brain death and organ donation, life and death which are related in the body or identify human individuality. Lock researched cultural differences in issues of organ transplants and definitions of brain death; she believes that human identity cannot be defined only in bodily terms, but must also recognise cultural effects.

In addition, some aspects of our human behaviour and propensity for diseases can be explained by genes. Thus, it should be natural rather than strange for artists to use DNA to express the identity of their subjects. Our physical appearance changes over time, but our genetic make-up does not, so a genetic portrait in some ways reveals a less transitory description of an individual. Traditional ideas about the role of 'nurture' have been challenged by genetic technology's explanation of the role of 'nature' in human behaviour. The success of DNA science in predicting behavioural and medical conditions has led some people to look for a 'gay gene' as an explanation for homosexual behaviour. The mapping of the human genome has not provided us with such an explanation; we should not forget the importance of 'nurture' – or culture – and we should be wary of reductionist approaches to sensitive cultural issues.

5.2.2 Monsters

Images of the grotesque are commonly shown in artworks. Frances S. Conelly explained that the grotesque has become important in the visual arts since the early nineteenth century. The re-emergence of the grotesque may be considered to have a parallel with such developments as psychoanalysis, photography, mass media, science and globalization. The main characteristics of grotesques are a lack of fixity, stability and order. Conelly (2003, p. 5-20) suggested that the grotesques can be understood as modalities which are at play on the boundaries of what they do. They exist in relation to a boundary, convention, or expectation. Connelly commented on the effect of the grotesque on art in her book:

> **The grotesque permeates modern imagery, acting as punctum to the ideals of enlightened progress and universality and to the hubris of modernist dreams of transcendence over the living world (Connelly 2003, p. 10).**

The first transgenic animal, the so called ‘Harvard mouse’, with oncogene[1], was successfully generated in 1988 (Muller et al., 1988). Some people are understandably concerned about the possibility that animals and plants with altered genetic characteristics could threaten our environment, our health and our food supply. Animal welfare groups feel that genetic manipulation will lead to increased animal suffering. Others believe scientists are, in a sense, ‘playing God’ by shuffling genes from one species to another. Still others are more concerned that scientists will use these techniques on humans.

This concern surfaced most visibly in February 1997 when researchers in Scotland announced that they had successfully cloned an adult sheep, producing Dolly, a younger, genetically identical ‘twin’ of the original (Wilmut et al., 1997). The possibilities of genetic manipulation have also reawakened an interest in monsters and mutants in contemporary culture and visual art.

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[1] An **oncogene** is a modified gene, or a set of nucleotides that codes for a protein, that increases the malignancy of a tumor cell such as cancer.

There are some artists, such as Jake and Dinos Chapman, Joel-Peter Witkin and Charles Ray who have reflected on this kind of cultural trend in their work. The visualisation of monsters and mutants is varied among artists; their visions of monstrosity or mutagenesis characterise their concerns with such technologies. It would be helpful to grasp the intent of artists and their interest in grotesque imagery.

In an interview with *The Journal of Contemporary Art*, the Chapman brothers mentioned:

> **One thing for sure is that "humanity" and "monstrosity" are not dislocated as a duality, are not even related equivalents but the same…. Our organisms are genetically mature and dislike being called children. They wear sneakers so that they can run fast like super- powered nomads (Chapman, http://www.jca- online.com/chapman.html).**

The Chapman brothers' *Zygotic Acceleration* is about sexualisation of children who live in the world of advertising and fashion. Wearing the same sneakers shows that contemporary culture makes no individuality or identity. The children in the sculpture look like each other and parts of their bodies are positioned wrongly. It expresses the potential shock and confusion that the bio genetic could produce in the next generation (Saatchi Gallery 2003).

Joel-Peter Witkin considers issues of morality as central to his photographs. He finds beauty within the grotesque, dwarfs, and people with odd physical characteristics. *Female King* (1997) is one of his photographs which is borrowed from 19^{th}-century painter James Ensor. In this painting, woman who is overweight and strong sits on a chair. Witkin intended to express the woman's great power and courage in this photograph. He represents the beauty of the grotesque which is taboo in our society (Palmer 1997).

Family Romance (1993) by Charles Ray, for example, is a typical artwork employing grotesque concepts. The group of sculptural pieces presents one family which has become the place of disorder and chaos, transgressing the principles of reproduction. He made the father, mother, boy and girl hold hands, each one as a normal family. But each individual is exactly 135cm in height and is naked. The parents are smaller than normal, the children are enlarged. His sculptural pieces represent notions of reproduction as affected by biotechnology (The Museum of Modern Art 1999).

The possibilities of biotechnology research make the future unpredictable or uncertain. In other words, biotechnology leads to a double-faced future with bright and dark sides that can either cure and create, or kill and destroy. Furthermore, it is hard to define what is natural or not, what is normal or not. Anxieties about the possibilities of biotechnology lead us to think seriously about our normality of the body in future society.

There are two representative images of science; pictures of Einstein with a smile and Frankenstein's monster with a scar on his face. The former shows a positive image, the latter a negative one such as the misleading of science or technology to destroy civilisation. As we know, the genetic revolution has questioned our concept of what is right or wrong, particularly in human reproduction fields such as embryonic stem cell research. Many artists have explored these anxieties about the body and the ways in which biotechnology could be a horrifying new development.

Even though the anxiety about new technology can explain, to some extent, the reason why grotesques are shown in contemporary art, it will be necessary to consider the relationship and communication between art and science for our society.

Denna Jones, a curator of the Two Ten gallery in the Wellcome Trust UK, commented on this aspect of communication, when scientific discoveries and developments are employed in artwork. She points out that artists with these topics play a role in a way for the general pubic to find out what scientists are doing and to start debate. She believes that bringing to the fore debates about current genetic research is an essential role for artists, rather than to explore the way it is right or wrong (Jones 2002).

5.2.3 Transgenic

Artworks using transgenic technology are closely related to the grotesque. While grotesque artworks usually reflect or focus on the fear of technology, transgenic art actively or directly employs their techniques and produces new types of artwork never seen before.

There are reasons for the existence of transgenic images in visual art today. As discussed above, transgenic animals and genetically-modified plants are a direct consequence of technologies which threaten the purity of the species. In other cases, they symbolise the capability to extend and transform life. Currently, transgenic researchers have become the subject of political, religious, and ethical discussion. It means that the transgenic issue has moved beyond the field of science, and is affecting our present society already.

Using the benefit from the discoveries of science, some artists find new biomorphic forms and materials in biological models, whose discoveries provide experimental source material for them. Visual artists like Eduardo Kac and Paul McCarthy have used this type of discovery as references in artworks influenced by transgenic experiments. Frank Gillette and Eva Sutton have represented the wider transgression of boundaries in this age. Even if contemporary art reflects a certain amusement at defying rationality, some artists express anxieties with transgenic science.

This section discusses artworks made by current transgenic artists and the cultural aspects of transgenics. Eduardo Kac is one of the artists of the transgenic art, which is a new art form. In his first transgenic artwork, *GFP Bunny*, he collaborated with geneticist Louis-Marie Houdebine in 2000 to create a rabbit called Alba which includes a gene that makes it glow green under UV light. This technique is usually used by scientists for research in the genetic engineering field. He used this science method to create transgenic art. He had an exhibition in which the GFP Bunny and he stayed in the space where people came and saw their interactions (Becker 2000).

Kac, as a transgenic artist, mentioned that he is not interested in the creation of genetic objects. He is more interested in the invention of transgenic social subjects. He also explained that

> **Transgenic art is not about the crafting of genetic objects of art, either inert or imbued with vitality. Such an approach would suggest a conflation of the operational sphere of life sciences with a traditional aesthetics that privileges formal concerns, material stability, and hermeneutical isolation. Integrating the lessons of dialogical philosophy and cognitive ethology, transgenic art must promote awareness of and respect for the spiritual (mental) life of the transgenic animal (Kac 2000).**

Another artist, Paul McCarthy, intends to explore our desire of consuming, and relationship to biotechnology in contemporary society. He made an installation entitled *Tomato Heads* in 1994, in which three male figures have a big tomato head instead of a human face, and he put gardening tools and giant carrots including rubber vaginas and penises into the figures and floor. His hybrid figures, which are the union of mixing parts, represent the dark side of violent transformation in biotechnology (Nelkin 1996).

As McCarthy expressed in *Tomato Heads* transgenic technology, Alexis Rockman, who has been interested in natural history, also gives the viewer an understanding, past to present of agricultural development. Particularly, one of his paintings, *The Farm* (2000), represented plants and animals that have changed their shapes and will change faster along with developments in biotechnology. He mentioned:

> **In The Farm I am interested in how the present and the future look of things are influenced by a broad range of**

pressures- human consumption, aesthetics, domestication, and medical applications among them (Rockman 2002).

The artists mentioned above take an ambivalent position to a human future influenced by advancing biotechnology. However some artists, for example, Eva Sutton, show another aspect that seems to be related to the grotesque. She created imaginary animals called *Hybrids* for her installation in 2000. These imaginary animals are mutated and hybridized monsters which combine different species into one body using a computer program, such as a dog head combined with a bird body and horse bottom. Her intention is to make these hybrid monsters as a possible result of genetic engineering experiments that could go wrong in the near future. Her imagery gives the viewer an image of biotechnology and bioengineering in terms of fairy tales, and myths (Sutton 2002).

Is transgenic art emerging as a new type of art at this moment? Let us look back at art history. In the early 20th century, Marcel Duchamp's readymade objects broke and extended the traditional concept of sculpture in which artists cast or carve three dimensional objects. His readymade objects opened up a new form of sculpture. Since Duchamp, artists have developed a variety of ways to visualize their themes or emotions. In 1968, the art historian Jack Burnham published his book *Beyond Modern Sculpture* which predicted a new form of art as a "living realty" after the 20^{th} century (Lynton 1970). He imagined that the development of science will break down the psychic and physical barriers between art and living reality and give an opportunity to create new forms of sculpture. Transgenic art could be one of the new art forms as predicted by Burnham.

Another aspect of transgenic art should be considered: Carol Becker explained that the artist's role for transgenic art (like Eduardo Kac) is as an educator, scientist and social critic as well as artist. Kac not only started a new art form, but also extended the role of artist (Becker 2000). This is a very important point in terms of Sci-Art or art itself. Even though the social role of art as education and communication among different worlds is a valuable point, the importance seems to be overridden compared to the self-expression of artists and other human activities.

5.2.4 New Eugenics

Successful cloning using somatic nuclear transfer in mammals, such as Dolly the sheep in 1997, provided scientific capabilities for the selection of traits and even for the 'breeding of better people'. Historically, the technology of artificial insemination had already started in the late 20th century. Since the first test-tube baby, Louise Brown, was born in Britain in 1978, IVF[2] technology led to the creation of families that naturally would not have existed.

Professor Robert Edwards, who helped create the world's first test-tube baby called Louise Brown in 1978, stated in a newspaper interview that "cloning, too, will probably come to be accepted as a reproductive tool if it is carefully controlled" (Schmickle 2001). The world's first 'designer baby', Adam Nash, was born on 29 August 2000 in the United States. He was born after genetic testing selection at an early embryonic stage to provide a cure for his sister Molly suffering from genetic diseases (Nerlich et al., 2003).

These kinds of advanced and developed technologies using DNA-related science consequently lead contemporary artists to explore identity, heredity and destiny in their images. They draw from eugenics and they convey concerns about the perpetuation of family, its history and blood lineage. Most artworks with the concept of eugenics describe a new type of human reproduction, rather than the selection for good population as in the early 20th century (which was discussed chapter 3).

Suzanne Anker is an artist and one of the leaders in art related to science and technology in New York, USA. She is interested in genetic science, especially in embryo transfer and genetic engineering. One of her art pieces, *Material Powers* (1999), expressed the ideas of a 'test-tube baby': two flasks, one with a

[2] In vitro fertilisation (IVF) is a technique in which egg cells are fertilised by sperm outside the woman's womb.

foetus and one waiting its foetal implantation, represents the transfer of embryo, and is seen against a background of chromosomes which was reflected onto and refracted by the flasks. Making babies in the laboratory is expanding the old way of making babies and breaks the concept of family. Her work addresses issues about reproductive technologies like 'designer babies' in our society (Anker 2004).

Adam Fuss's *Invocation* (1992) was exhibited in the Gallery of Art and Science at the New York Academy of Science in 2004. The title of the show was *Reprotech: Building Better Babies?* It investigated the positive and negative possibilities of reproducting new life curated by Susan Anker. Fuss used a traditional photogram, which does not use a camera to take a photograph, but uses light to gain the image from real object without using lenses. He positioned a baby in a shallow tray of water and captured the outline of the baby's body and its movements by the photogram technique. He explained that this image gives an impression of a baby in the womb (Anker 2004).

In contrast, Zhang Xiaogang touched on another aspect of eugenics. He was interested in birth control by government policy in Europe and America, and the consequences. His portraits are all about family and the notion of identity within communist Chinese culture. The faces in his paintings do not show any emotions, names or time. He painted a series of individual histories in a limited style (Chang 2004). His series *Bloodline* began in 1990, coinciding with the rapid growth of consumerism in China. All family members (father, mother and one child) are linked by a red bloodline in his paintings, in which the mother and father are shown in black and white, and the child figure is shown in colour. The families in his pictures show no emotion; we see an unnatural situation in place of the usual happiness.

The child in his family paintings is always a boy. Each parent is allowed only one child by the Chinese government. Most parents prefer to have a boy. Xiaogang intends to show how the traditional family is preferable to the modern 'revolutionary family' where all individuals are brothers and sisters, as proscribed by Chairman Mao. Xiaogang's art explores these new eugenics and the problems caused by clashes between the restrictions imposed by a state and the freedom offered by these new technologies.

The 'designer baby' is no longer just a fictional idea. The power of creation once believed to be the sole province of God is now in the hands of scientists. Development of genetic determinism, genetic tests and gene therapy can reduce suffering caused by genetic disorders. In fact, the potential to cure the diseases increased after the completion of the Human Genome Project and advances in cloning technology. It also gives us hope of saving babies who could not survive without these technologies. On the other hand, it can make us scared to think about the future of human identity and immortality. It could be that having a baby is like choosing the kind of car we want – what colour and shape it should be. People are wondering how far we are willing to go to have a 'normal', 'perfect' or 'genius' child.

Susan Anker questioned these serious issues of our life and society:

> **With the bio-printing of replacement organs and tissues on the research horizon, at what cost is this quest for immortality? What social consequences are in store when wombs can be rented through surrogacy contracts and children become the genetic product of three parents? When virgins can give birth and corpses can be fathers, what's next? (Anker 2004).**

These questions are not only Anker's questions, they are also are our questions. Furthermore, there are more questions we have to think about: how do we perceive an original or copy, the value of unique personhood, or for that matter the unique status of a work of art?

5.2.5 Commodity

Commercial values have returned to the visual arts since the 1980s, and artists have approached the consumer culture in various ways. Some works have glorified the banality of kitsch by using the signs and symbols of the commodity.

Chrissy Conant and Helen Storey draw their images from the state of science and its commercial direction. Others, like Larry Miller and Bryan Crotchett, believe that living beings should not be used as products or instruments. Their varied perspectives reflect the broader public ambivalence about biotechnology's unravelling applications. Frank Moore reflected the agonizing complexity of questions by his painting, *Oz*. This painting can be seen either as glorifying the worth of genetic research or as an advance warning of genetic engineering.

Chrissy Conant produced into packaged goods "Chrissy Caviar" using her own eggs as a commodity, in 2001-2002. She borrowed an image from beluga caviar, which is one of the world's greatest delicacies, and made her own product to express the reproduction of the body in the market. Creating a new product as an artwork, she put one of her eggs combined with human tubal fluid in a jar instead of fish roe and made a new label which shows her body instead of a fish. The process of making "Chrissy Caviar" followed the scientist's method of using mouse or human eggs in the lab. She explained the aim of making art with her body by collaboration with technology to satirize the selling of women's eggs in contemporary society (Conant 2003).

Larry Miller has focused on issues of human lineages, identity and the coding of DNA in genetic science since the late 1980s. Miller's *Genetic Code Copyright* (1992) focused on question of the ownership of DNA and commercial applications of genetic technology. He created a certificate of the genetic code for humans and published it all over the world. He tried to bring issues of individual identity, genetic ownership and ethics raised by genetic technology to public debate (Leffingwell 2000).

Frank Moore's painting, *Wizard* (1994) is a futuristic landscape of a medical establishment, with pills and dollars on the ground. In the painting, there is one man with a white-coated scientist who is identified as Dr. Jean-Claude Chermann (a co-discoverer of the HIV virus), and are with a retinue of white lab rats. In his painting, Moore described the dark side of the scientific research, which is an important method to improve human life. As he was HIV[3] positive when he painted *Wizard*, he had an idea that genetic engineering research is going to change every aspect of our lives, and that it needs people's attention in order to keep research on track (Sievert 2002).

R. Henig (2004) gives the example of Chrissy Conant, who produced the packaged goods "Chrissy Caviar" as art, and points out that one role of artists who visualize and represent science is to bring the debate to the general public.

> **Explaining the implications of reproductive technology by using her own body as a canvas - this is why a society needs its artists, to take its developments and transgressions to their logical, and sometimes even illogical, conclusions (Henig 2004).**

Unlike scientists, artists do not find right or wrong answers. Artists contemplate scientific ideas and try to share and discuss scientific issues. Henig explained that while scientists inform their research with diagrams or writing which the public hardly understands, artists visualize via paintings, sculptures or installations which people can more easily understand and about which they are able to form their own opinions about.

Critical Art Ensemble (CAE) shares the view with Henig that artists should provide critical public debate and form a bridge to biotechnology and show both the positive and negative sides which relate to funding and commodity.

> **The utopian rhetoric of the creators, manufacturers, and promoters of scientific invention is relatively hard to argue with, because of a popular perception that the public (nonspecialists in biology) cannot comprehend scientific knowledge at an advanced enough level to be able to validly comment on scientific claims and initiatives (Critical Art Ensemble 2000).**

[3] Human immunodeficiency virus (HIV) is a retrovirus that causes acquired immunodeficiency syndrome

CAE (2000) suggested that scientists should inform and discuss their views with people such as artists, activists and students of different levels, because they believe that such people are able to make valid contributions. From the viewpoint of capitalism in the globalised world, anything can be traded. Thus, it is not strange for artists to express their concerns about commercialised societies and warn about the negative issues, and these concerns expressed through art are essential for communication with the public. These kinds of artworks can express negative, positive or neutral views of science and technology, and do not need to decide which views are right or wrong. They just raise questions and show what is going on now.

5.3 Conclusions

Finally, I would like to discuss a new movement in art that uses science as its subject. Earlier, I introduced five different groups of artists whose theme was inspired by DNA, genes, or genetics. Each visualized in various ways new scientific research, some creating new forms of art with new scientific technologies, and some representing the negative aspects of scientific research. It would seem only natural that artists are interested in DNA and its effect on human life and society, because of art's traditional association with themes of identity.

Until the end of the Renaissance, there was hardly any distinction between art and science. For example, Leonardo da Vinci was both an artist and scientist himself, and similarly Galileo Galilei was a scientist and musician. One reason a person could study science and art at same time was that there was not too much knowledge to understand. As technology developed with such tools as the microscope and the computer, each subject has become more complicated and specialized. Alfonso Niquori, Professor of physical chemistry at the University of Rome, pointed out that there is one important reason for the division of art and science:

> **The romantic idea that a scientist should not use imagination but only rigour, and that an artist must not use rigour but only imagination is in my view completely wrong – I**

think that a scientist without imagination is a very bad scientist and an artist without rigour is a very bad artist. Today, I think that this link has a chance of being re-established again (Wijers 1996, p. 166).

Niquori criticized the romantic idea of scientist and artist separated in imagination and rigour. In his opinion, scientists and artists should have both imagination and rigour. Previously, I described the value of imagination in scientific research, focusing in particular on Watson and Crick's work on DNA structure in chapters 2 and 3. Now, I will explain in more depth how the imagination is used by artists and scientists.

Imagination is a kind of psychical power that can describe or visualise things which have no visible form. Artists use their imagination to create their artwork and, as part of the human being, imagination provides the grounds to differentiate humanity from other creatures. I assume that most of the artists in this chapter visualise their ideas with their imagination of DNA and the future of our society which could be unpredictably changed by genetic technology.

At the end of the 20th century, there are an increasing number of artists who engage with science subjects. They believe that Sci-Art is a new movement for the 21st century, in which science will be considered as a crucial domain to explain our society and human activities. However, some people doubt that Sci-Art should have a significant status as a field in art precisely because of its educational intent and its close association with science. On the contrary, I believe that as anything can be a valid subject of art, the use of scientific subjects in Sci-Art does not disqualify it from having art status.

Sci-Art allows the ordinary public to understand complicated science and technology more easily by illustrating, simplifying and raising social issues. Sci-Art is located in the indeterminate and ever-expanding border between science and art. If art can be defined as a subject exploring uncertainty for forming new concepts about human and nature, Sci-Art should also be considered as having potential for artistic activities.

The next chapter will analyse the importance of collaboration between art and science in education. This will include a report on questionnaires about Sci-Art which was carried out with students from Trinity Catholic School. The questionnaires were designed in two parts: 1) the question as to how students regard science and art, and 2) their attitudes towards Sci-Art.

Chapter 6

Collaboration between art and science in education:

A case study at Trinity Catholic School

6.0 Introduction

The previous chapter (chapter 5) demonstrated there has been a great deal of work on science and art. In this chapter, I will attempt to examine the benefits of collaboration between science and art. This chapter will review my residency at Trinity School by way of further understanding the possibilities that art and science exchanges can bring. Before moving to the central part of my analysis, it is worth taking a quick look at science-art collaboration projects and the importance of the interdisciplinary exchanges of thoughts and processes.

Sci-Art is a relatively new and exciting area, bringing artists and scientists together to work on ideas that have common themes or problems. Thus several foundations and organisations promote many such partnerships and projects including artists-in-residence schemes (see Table 2). I will argue that Sci-Art can promote public engagement with science and raise important questions about how science affects our world.

	Title of Organization	Activity
1	The Daniel Langlois Foundation for Art, Science and Technology	Established in the spring of 1997 through an endowment provided by Daniel Langlois. The Foundation is a private non-profit organization whose scope of activity is international.
2	Wellcome Trust	Funds scientists and artists to research and to produce projects that reflect contemporary practice in each discipline. Emphasis on science-art collaborations.
3	Art & Science Collaborations, Inc. (ASCI)	A wonderful New York City based global non-profit organization that has an online matching tool.
4	The ArtSci INDEX	Seeks to help facilitate collaboration between scientists and artists. They also host conferences, produce art exhibits, and the monthly ASCI eBulletin.
5	Seen & Unseen	Initiated by Helix Arts in England, encourages and promotes examples of how communities can work with artists and scientists to tackle their own pollution problems
6	The Arts Catalyst (UK) the science-art agency	Promotes and connects artists and scientist led projects. A heavy focus on space, biotechnology and high tech science. Some interesting projects.
7	YLEM - Artists Using Science & Technology	An international organization of artists, scientists, authors, curators, and art enthusiasts who explore the intersection of the arts and sciences.
8	Leonardo/ISAST	Serves the international arts community by promoting and documenting work at the intersection of the arts, sciences, and technology, and by encouraging and stimulating collaboration between artists, scientists, and technologists.

Table 2 Foundations and organisations which support Science and Art collaboration

Sci-Art emerged from a socio-cultural context that has provided major support to collaborations between artists and scientists since at least 1996, when the Wellcome Trust launched their Sci-Art scheme. In 1998, the U.K. National Endowment for Science, Technology and the Arts was created, and in 1999 the Sci-Art Consortium was established, comprising no fewer than five major funding bodies coming together to support art and science projects. At the end of 2001, the

Arts Council England and Arts and Humanities Research Council agreed to set up a new joint funding strand for interdisciplinary research fellows working across science, technology and art (Ferran et. al. 2006; British Council 2003).

The Wellcome Trust, an independent research-funding charity, was established under the will of Sir Henry Wellcome in 1936, and is a leading organisation for Sci-Art projects. The Wellcome Trust has been seeking to engage many types of audience in medical science and its social context. The Sci-Art project by the trust started in 1996 because they believed that collaborative and interdisciplinary practice across the arts and sciences can help to provide new perspectives on both fields.

Ken Arnold curated many major Sci-Art exhibitions for many years as head of the exhibitions department at the Wellcome Trust. He accurately articulated the necessity of these projects; firstly, science has provided some artists with inspiration in the areas of medium, message and location; secondly, the world of science can gain in many different ways from the arts, and bring new perspectives and insights; finally, the true power of science and art as a union is that the union can build a more engaged relationship with the public, not the practical breakthroughs (Arnold 2005).

C.P. Snow argues that students majoring in science should study art subjects, and *vice versa*.

> **This study could be grafted into any of our educational systems, at high school or college levels, without artificiality and without strain. I dare say that, as usual, this is an idea which is already floating around the world, and that, as I write this paragraph, some American college has already laid on the first course (Snow 1963, p. 75).**

Snow explained that some American colleges had already started this type of interdisciplinary study by 1960. He claimed that the two cultures have to meet each other in an early education period (secondary college level) to avoid creating a gap between them. Since Snow pointed out the importance of crossover education 40 years ago, some educators have found that many students have difficulties with, and are less interested in, science subjects which have separated from other subjects. They share Snow's opinion that art and science should be interdisciplinary learning subjects. It is important to examine why students are not interested in science subjects and how art can increase students' interest in science subjects. Part of my residency experience was to observe whether art can increase students' interest in science.

6.1 Sci-Art in School and Laboratory

I worked as an artist-in-residence and lecturer-in-residence from 1st October 2006 to 5th February 2007 in the Trinity Catholic School, Leamington Spa, England. During my residency, I collaborated, two days per week, with selected key stage 3 students. My artworks have focused on life sciences, in particular the structure of DNA. With the students, we were producing sculptural structures based on the iconic three-dimensional structure of DNA, exploring the theme of personal identity. This work was shown in the "Laboratories" exhibition that was held in Trinity Catholic School from 5th Feb. 2007 – 19th Feb. 2007.

To better understand this "Laboratories" project, I would like to briefly introduce Trinity Catholic School. The school has both Technology and Arts status and has been awarded an Artsmark Gold award. The school also has its own Sixth Form College on site, so the age-range of pupils is 11-18. Since 1980, the school has had an annual art exhibition with a variety of subjects. This year, the theme of the exhibition was the 'Laboratories'. Clearly, the school is already predisposed to interdisciplinary practice and, as such, my findings are particular to this context and school.

It may be useful to start out by describing this program. Firstly, some of the A-level students explored the practice that occurs in scientific laboratories. The students discussed the moral, social and ethical issues relating to scientific exploration. Secondly, Sue Williams, a biology teacher, dissected a rat in the art department. Art teacher Sheridan Horn recorded the whole process, and many students took photographs for documentary purposes. After the dissection, the students made drawings of their photographs, and then the recorded film was presented in the exhibition. Thirdly, students were encouraged to independently investigate or analyse a variety of artists whose works relate to scientific themes or issues. They also discussed how artists presented their work and how it shows their understanding of science.

The project attempted to provide the students with a new perspective of the relationships between science and art. To accomplish this goal, artists-in-residence and teachers collaborated with students to generate several artworks. These are described in the next section, and my own work will be discussed in the following chapter.

The following artists contributed to the 'Laboratories' exhibition: Grace Newman, a sculptor, explored biomedical issues using mixed media, including medical ready-mades. During her residency at Trinity School, she encouraged selected key stage 3 students to see the sights of nature through making cellular structures. Another artist-in-residence, Lucy Halliday had worked with students from key stages 4 and 5, and explored the sense of proprioception[4] and the phenomenon of phantom limbs, producing a collaborative piece using film and sculptural processes. Eva Smets had been in the school one day per week, and responded to issues relating to cloning. Miriam Zvelking worked with key stage 3 students exploring 'the scene of the crime'.

Teachers also contributed to the Sc-Art project: Gill Jopia, an art teacher who employed the concept of clothing as an autopsy specimen, and performed anatomical dissections on a wedding dress using it as a metaphor for the break-up of human relationships. Sheridan Horn, head of the art department, had played the role of a parapsychologist called Professor Fluke during the project. She produced a mock-up of a small research laboratory entitled 'The Department of

[4] Proprioception is the sense of the relative position of neighbouring parts of the body. Unlike the six exteroceptive senses (sight, taste, smell, touch, hearing, and balance) by which we perceive the outside world, proprioception is an interoceptive sense that provides feedback solely on the status of the body internally

Parasitological'. It showed a range of aspects of human life such as co-dependency, mortality and medical achievement.

6.2 Workshop using science as a resource for creative art

In this section, I would like to begin by presenting the outline of the workshop that was carried out during the artist's residency programme at Trinity Catholic School, focusing on the understanding of relationships between art and science and the importance of science as a potential resource for creative activity.

It is commonly considered that art and science are at opposite ends of the educational spectrum because similarities and differences between two academic disciplines seem to be misunderstood and at variance with each other. Furthermore, as I presented above and in chapters 1 and 3 (science and art, DNA icon), Sci–art is not fully established yet, and is still not regarded as a visual art genre. However, it represents social and moral issues to the public, and many artists express their concepts of science in the post-genome era. In this regard, the consideration of the relationship between art and science is necessary for potential roles in art. In particular, most interdisciplinary education in art and science are carried out in science-based schools or institutes, focusing effects or influences of art on science such as inspiration. However, science is not considered as a subject for creative art *per se*. Thus the aim of this workshop is to provide another aspect and understanding of science for art, particularly focussed on DNA and Biotechnology. To do this, the workshop is built upon three major steps as follows:

1. Basic understanding of DNA structure and history of the discovery
2. Discussion of the importance of DNA and the potential roles in our life
3. Group studies and art production using DNA as an artistic theme

Firstly, I presented and explained using slides and video to help the students gain insights into the discovery of the DNA structure including the basic structure. The double helix consisted of four different base pairs (A, T, G, C), the dynamic activities such as DNA repair, replication, transcription, and translation.

Moreover, the procedures of the discovery of DNA structure were also presented. As described in the previous chapter, the double helix structure was discovered by speculative imagination using previous accumulated results published by other scientists, rather than by experiments using chemical or physical methods by Watson and Crick. Through this lecture, imagination and creativity which are considered as critical elements in art are important in science as well as art. I demonstrated to the students that interpretation using imagination guides scientists to propose novel scientific models (creativity), which are consequently proved by experiments. My intention, then, is to offer a new perspective for similarities between art and science.

Secondly, we discussed why the discovery of DNA structure is important and how the developments of technologies using DNA such as recombinant DNA, transgenetics, somatic cell nuclear transfer (Dolly the sheep) have affected our life. Human cloning was also introduced. This study was intended to broaden students' horizons in understanding the effects of science on our life and why scientific findings such as DNA can be used as a resource for creative art.

Thirdly, artworks were produced as a part of the artist/lecturer-in-residence programme, focussing on "IDENTITY" related to DNA. The first four groups participated in the production of three-dimensional sculpture. Various materials were deployed in articulating these structures. From differently-coloured autumn leaves to laboratory ware such as glass pipettes and test-tubes material 'values' were explained. The particular material associates, leaves and scientific apparatus, were part of the interdisciplinary nature of the workshop. The students brought their own nails, urine and hairs to present their identity and showed their performance about their identity.

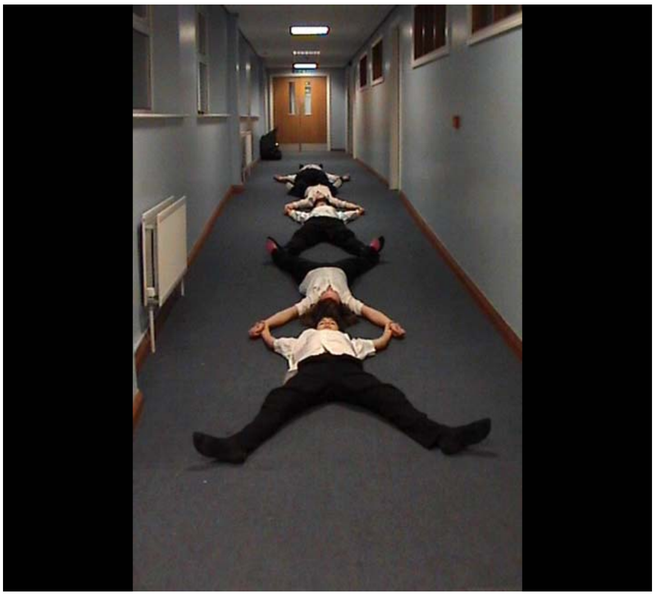
This art production was carried out in October 2006. Thus fallen leaves on the school ground were collected and dried for one week. The dried fallen leaves and laboratory wares were attached using glue guns to the double helix shaped flame that was made of chicken wire (Figure 27a, 27b). The processing of art production was very exciting and interesting to all participants, taking their own identity and collaborating with others to create artwork using a common theme -

identity related to DNA. The leaves and lab wares containing their material identity such as nail, hair, urine and even their pictures, tried to represent their identity in the big DNA double helix (Figure 28).

Figure 27a and 27b Processing of 3-D art production

Figure 28 Final art work of 3-D sculpture using laboratory ware and natural materials.

The second group of students produced a video. The second group initially brought in and presented information in relation to their identities through basic descriptors and performances (Figure 30). These were more of an identikit, showing colour of eyes, birthdays etc. The students presented these through performances in the manner of a police 'mug shot'. Juxtaposed with this identity expression were images representing embryonic developments which were provided by Inchul Choi, a PhD student studying animal development and biotech at the University of Nottingham (Figure 31). The resulting video of the performance with the 'mug shot' stance in relation to the biotech images enabled discussion around the nature of biology and identity through both the subjective and the rational forms of expression (Figure 32). The project also enabled me to discuss ideas around nature/nurture. The ensuing discussion focused on differences and connections between biological identity and sociological identity. The final video document was shown in the same place as the 3D structural work (Figure 33).



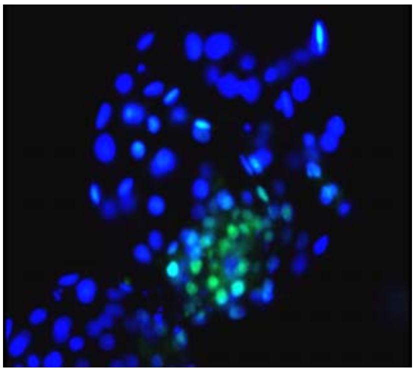


Figure 30 Performance of students

Figure 31 Image of embryonic developments

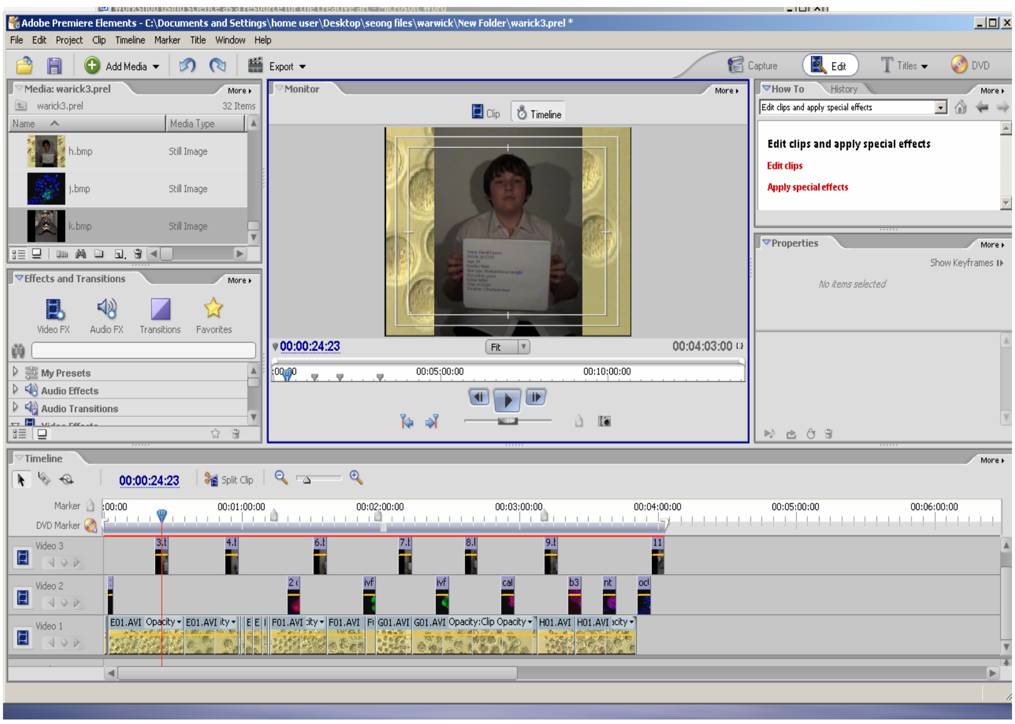


Figure 32 Production of video using identity and embryo development.

Figure 33 Installation Laboratory

6.3 Questionnaire

In addition, a questionnaire was used to enable me to determine students' perspective of art and science. Students involved in the Sci-Art project from 11 to 18 years old at Trinity Catholic School responded to the questionnaire at the end of the project. In total 128 students answered the questionnaire, which consisted of 14 items. The function of the questionnaire was to determine some contextual knowledge from within the group that I was working with. In this manner, the questionnaire was viewed as a guide to the particular situation that I was working in. It should not be viewed or read as a general questionnaire. Its function was to help me understand better the views of the people I had been working with.

In other words, I have examined the hypothesis in which the students, even if they had taken programmes about art and science, had incomplete or little knowledge or understanding of intrinsic characteristics of art and science. Considering the ages of the students who participated in the programme and their ability to answer, closed (forced) choice-format was used for collecting information such as understanding or knowledge about science, particularly DNA, and preference about interesting fields in science. I used this particular structure because this format is easy to fill in, record and analyse results quantitatively, and report results, although more comprehensive responses and results can be obtained by open format (Leung 2001).

Furthermore, differential scales type, for example 3, 2, 1, 0 for interesting, interesting but difficult, not interesting and difficult, respectively, was applied to determine the overall tendency within each group and whole groups. To minimise bias of responses or non-responses, the questions were established by the following rules, 1) short and simple sentence, 2) precise question, 3) from general to particular (top-down or narrow-down), 4) from easy to difficult. To obtain valid responses or maximise the proportion of subjects answering, I also gave lectures about the substantial necessary knowledge about science, and explained the purpose of this survey prior to in issuing the questionnaire (Barton 1958).

Admittedly, the results of the survey are not statistically representative. Also, the nature of the questions is simplistic. I felt this was necessary, given the differing age groups I was working with, and that the questionnaire was simply a way of focusing views and thoughts. This was a very specific group of students and as such the value of the survey was localised. Since the group was predominantly engaged in 'art' activities, this would further shift the results of a survey. However, I felt it would be helpful to look at the results of the survey in order to understand how this group of students felt about and understood both the possibilities of science and art in collaboration and how each separate subject was viewed as an autonomous element. For the purposes of information-giving I have placed all the responses and analyses in the appendices.

The questionnaire can be categorised into three parts: the first part includes general questions concerning science and art (Table 3); how they think about the two different subjects and what kind of subject they are interested in; how they think about DNA structure and so on. The second part is directly related to Sci-Art areas. The third part surveyed what they think about the intrinsic meaning of science and art.

Table 3 Questionnaire

	No	Questions
General question about science and art	1	What do you think about science?
	2	Which areas of science are you most interested in?
	3	Have you seen the structure of DNA before this class?
	4	When you see the DNA structure, what does the structure remind you of?
	5	What do you think about the structure?
	6	Do you agree science will improve human life in the future?
	7	What do you think about art?
	8	Which kinds of visual arts do you prefer to express your ideas?
Relationship between science and art	9	Do you agree art can help people to understand science?
	10	Do you agree science can have new artistic agendas?
	11	Do you agree that collaboration between art and science is necessary and attractive?
	12	Do you agree Sci-Art improves the communication between two different areas?
	13	Do you agree both science and art contribute to the shaping of the future in contemporary society?
Understanding concept of science and art	14	Mark A for art, S for Science, and B for both in the following elements that represent characteristics of Art or Science, or both: careful observation, creativity, use abstract models to understand the world, aspire to create works that have universal relevance, seeks aesthetic response, emotion and intuition, visual or sonic communication, seeks knowledge and understanding, reason

6.4 Discussion

In general, the results show that people think that science will improve our life, and that art can allow people to become more familiar with science. In many ways this bears out the intentions of the Wellcome Trust in its belief that art can bridge science to people and give insight to science itself. Consequently, collaboration between the two subjects is desired, and Sci-Art could facilitate the processes. However, the interactive movements of science and art are still considered as unfamiliar or foreign things to us, though the majority of people think the movement would be beneficial for science and art, as well as our society in general.

Stephen Wilson described the differences and similarities between art and science in his book, *Information Art* (Wilson 2002 p18-20). His analysis is summarised in Table 4. As I discussed in the previous chapter (Art and Science), it is not simple to define the concepts of art and science. However, I think that Wilson's studies give convincing answers to many questions in regard to their differences and similarities. As he indicates, creativity is an important value not only in science but also art.

Table 4 Differences and similarities between art and science (adapted from Wilson, 2002).

Art	**Science**
Seeks aesthetic	Seeks knowledge and understanding
Emotion and intuition	Reason
Idiosyncratic	Normative
Visual or sonic communication	Narrative text communication
Evocative	Explanatory
Values break with tradition	Values systematic building on tradition and adherence to standards
Both Art and Science	
Value the careful observation of their environments to gather information through the senses.	
Value creativity	
Propose to introduce change, innovation, or improvement over what exists.	
Use abstract models to understand the world.	
Aspire to create works that have universal relevance.	

In my survey, most students (81%) thought that creativity is only found in art, and only 19% suggested that both art and science have creativity. Whilst understanding that this is not a statistically representative survey, it does suggest the dominance of creativity as associated with art. This result implied that they did not fully understand the creativity of science. This view of creativity is likely to be caused by misunderstanding the activities of science and a common tendency to separate art and science; probably most people tend to think of creativity almost exclusively in terms of art and aesthetic creativity (Westland 1969). However, as has been noted earlier (Chapter 1), human creativity is a basis of both art and science, which in turn contributes to our understanding of nature, reality and complexity.

According to C. W. Taylor's study, *Various approaches to and definitions of creativity*, there are more than 60 different definitions of creativity (Taylor 1988). Among them, the most widespread conception of creativity is that it is a product with novelty and usefulness. Thus creative activities result in producing or bringing about something partly or wholly new, investing an existing object with new perspective, imagining new chances that were never conceived of before and performing and producing something in a different new manner. Consequently this conception can be applied to different objectives, such as a person, a product and a process (Taylor 1988, p. 99-121; Rhodes 1961). With regard to this point, I hope to have shown that science is one of the creative human activities.

6.5 Conclusions

Up to now we have looked at various aspects of collaboration between art and science for the purpose of education. The question then arises as to why students are confused or misunderstand the activities of art and science. One probable reason is the tendency to separate art and science that has been going on since the Renaissance gave way to the modern age and art and science began to separate. E. O. Wilson (1999) indicated in his book, *Consilience: The Unity of Knowledge*, that the gap described by C. P. Snow between two cultures of the sciences and the humanities, including art, continues to exist today. For these reasons, I am convinced that to gain a better understanding of one subject, two different disciplines should be learned at the same time in school, comparing their similarities, differences, and interactions.

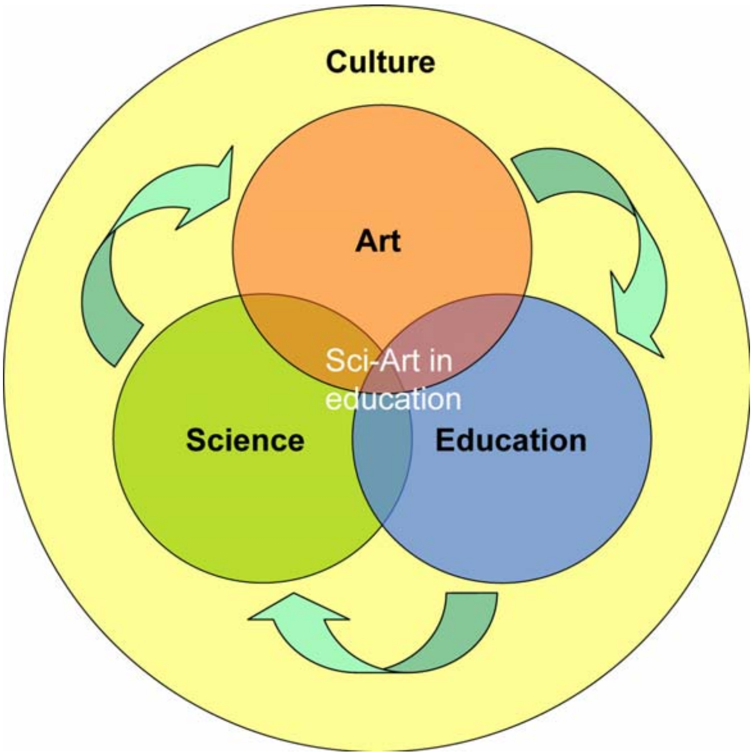


Figure 34 The necessity of collaboration between science and art in education.

As shown in Figure 34 , science, art and education have not only their own domains in our culture where human activities are reflected, but also intersecting domains. I would like to close by proposing that Sci-Art projects can be adopted as a new bridging discipline in education to improve communication between art and science, and to help understand their intrinsic and extrinsic conceptions.

Taken together, my research, including collaborative artworks with students and analysis of students' responses about this project, lays the foundation for future work or studies on the benefits of collaboration and how we can understand and discuss the gap between science and art.

I will also present my sculptures at the Centre for Effective Learning in Science (CELS) at Nottingham Trent University in December 2007. CELS is dedicated to creating a more relevant, accessible and achievable image for science within both the higher education and school communities. In this exhibition, my works as part of my PhD studies show how science can be creative, beautiful and inspirational as well as explore our lives and culture through the medium of sculpture. This exhibition is planned to support the strengths of a creative Nottingham (appointed as science city).

In the next chapter, I will introduce my artwork as the outcome of my research. As Sci-Art is new movement in art, I will attempt to prove how Sci-Art can be a powerful tool for communication with my sculptures and exhibitions during my PhD course.

Chapter 7

Art exhibitions based on interdisciplinary approaches to science and art

7.0 Introduction

In this chapter, I would like to introduce my artwork, in which I attempt to celebrate the beauty of DNA structure with an aesthetic view. Also, I hope to demonstrate how artworks exploring DNA can evoke meaningful speculation in the audience about the relationships between art and science, and to communicate this to scientists and artists, as well as the public. During my practice-based PhD research, I had several exhibitions and projects that were held in art galleries or public spaces in the United Kingdom as well as in Korea.

Before exploring my artworks in detail, I would like to mention briefly how I became interested in DNA structure as an art subject and as an expression of natural beauty and the intrinsic meaning of DNA structure and biotechnology. There are two significant inspirations: one is that I married a biotechnologist, Dr Seog Hyung Kim, who taught me the detail of DNA structure and discussed with me other issues relating to biotechnology. The other inspiration is *Endless Column* made by Constanitin Brancusi in 1907-8. When I learned about DNA structure in 1995, I was surprised by the similarity in shape and idea between endless column and DNA structure.

The *Endless Column* is composed of 16 modular elements of copper-coated steel, consolidated by a steel substructure. There are in fact 15 complete modular elements, the 16th constituting two half-elements, at the base and the summit of the assemblage. The basic modular element of the *Endless Column* consists of two square-based pyramids, truncated, or "decapitated," at the top, and joined at their widest parts. The column itself was assembled by joining the truncated heads of the modular elements.

Radu Varia said that the modular elements can be theoretically extended to create a linking relationship between ground and sky, or between humanity and the universe:

> **As a result, the modular elements that composed the *Endless Column* underwent a slight "in-breathing," comparable to invisible human and cosmic inhalation (Varia 1995, p. 238).**

Brancusi's only completed monumental space was the Tîrgu-Jiu Complex in Romania, inaugurated on 27 October 1938. The *Endless Column* is one of the most important sculptures there. The whole space was intended to be a votive and funerary monument in memory of the soldiers who died during World War I. Other sculptures include the *Table of Silence* (a circular table surrounded by twelve circular hour-glass-shaped stools) and the *Gate of the Kiss* (flanked by stone benches placed on each of the short sides). In its intentions Brancusi's monumental circuit at Tîrgu-Jiu is comparable to the original goal of the early Egyptian dynasties thousands of years before. In their sculpture and architecture the Egyptians pursued an imperial, solar interpretation of their own destiny – a struggle to control the whole of space. The resurgence of ancient Egyptian themes in Brancusi's later work is an indication of his vision as he explained in the following comments:

> **A work of art expresses what escapes submission to death. […] this sculpture belongs to all time for I have stripped the essential form of all the features which could link it to an epoch (Varia 1995 p. 103).**

It is an important point that both the *Endless Column* and DNA structures involve ideas of how we view life: *Endless Column* is a poetic metaphor, but DNA structure is a fundamental material of life. The structure of repetition is an important element to express endless desire. It wants to continue forever. Both the *Endless Column* and DNA structure have associations with mortality and immortality: DNA is present in all living things, and all living things die.

Brancusi's sculpture is partly a monument to the dead. On the other hand, DNA is what survives us after we die, because it perpetuates the species. Similarly, *Endless Column* stands also as a memorial to the continuity of life.

Morphologically, the repetitive structure and continuity reminded me of human endless curiosity, and eternal life. The reason why DNA and biotechnology fascinates people is directly related to this curiosity. Thus, in my work, I intended to express this view of the structure of DNA and life using sculptural installation, and to evoke imagination and curiosity among spectators or participants. In this way, I aim to provide a new approach to understanding the two different disciplines, which can allow artists and scientists to grasp our uncertain world.

7.1 Art Exhibitions and Projects

The aim of this chapter is to explore the ways in which my artworks are conceived, developed, processed, and finally expressed. My work can be categorised into five themes:

1. Representation of DNA structure as a celebration of nature
2. Conception of DNA and visualisation
3. Collaboration with scientists and exhibition for the public
4. Exploring reality of DNA with fractal images
5. Sci-Art in education.

These themes represent the development of my art practice through this research project, and each will be discussed in detail in the following sections.

7.2 Representation of DNA structure as a celebration of nature

My solo sculpture exhibition, *DNA Structure and Human Desire*, was shown in the 1851 Gallery, Nottingham, UK, from 8th-30th November, 2004, and was sponsored by Nottingham Trent University, Bonington Gallery, and the Arts Council UK. The works were not replications of DNA structure but a personal perspective on DNA as a cultural icon. Professor John Newling described my works in the exhibition pamphlet:

> **She is inspired by visualisations of the molecular structure of the phenomenon of DNA. But this is not to imply that Kim's sculptures are replications of the double helix. They are expression of the form wedded to notions of abstraction and explorations that seek to dissect the twisted ladder as a means of personal expression whilst giving cognition to the iconic nature of her subject (Kim 2004).**

I was fascinated by the implications of the discovery of DNA for the future of humankind, and during the first year of my research, I started to express the double helix as a sculptural form. The use of sculptural media to create artworks is significantly informed by the traditions of sculptural practice itself. I chose to start by creating columns, and consequently needed to explore the use of the column motif in sculpture. Despite its antiquity, the classical order is still part of the contemporary vocabulary, and it has been subsequently enriched in European medieval art in the practice of fabrication and decoration in architectural settings. The research considered the relationship between the form and content of sculptured columns.

With regard to materials, John Newling mentioned:

> **Seong-Hee generally works in wood and stone: materials of permanence, materials of past generations. Perhaps she pursues marble and ash in the knowledge that her subject, whilst microscopic and fluid in nature is of all of us, an odd kind of absolute permanency that has always been us, but until 1953 was not visualised (Kim 2004).**

I make sculptures in wood and stone, which are materials of permanence and of past generations. Using a traditional method like wood and stone carving to express the subject of DNA, I produced a very special form of structure in my sculptures which are at one and the same time abstracted testaments to the visualisation of what we are.

In addition to this exhibition, I also developed a website in connection with my *DNA Structure and Human Desire* exhibition.[5] The website displayed digital imagery to contextualise photographs of my sculpture and replace an architectural setting with a virtually constructed space inhabited by other scientific images. To explain my works in more detail, I will review my thought processes in relation to the creation of seven sculptures that were installed in the 1851 Gallery.

7.2.1 *DNA Desire* and *DNA Endless 2004*

DNA consists of phosphorus, oxygen, nitrogen, carbon, and hydrogen. These elements are joined to each other with hydrogen bonds[6] and covalent bonds[7], and can be visualised with ball-and-stick models[8] that show the different size of each molecule. In these sculptures, I intend to express DNA as an iconic structure with a repeating helix form which can be interpreted as an endless column. With repeating forms and simplification of the very beautiful double helix, I described DNA in 3-dimentional and voluminous form rather than the linear form shown in Odile Crick's original drawing (Watson and Crick, 1953).

In two of the sculptures from the exhibition – titled *DNA Desire* (Figure 35) and *DNA Endless 2004* (Figure36) – the ball model is used as a motif. Using two different materials (limestone and ash wood), I attempted to explore their different textures. Both the materials and DNA originated from nature. Stone, for example, is firm, strong and hard; in contrast, wood is soft, warm and flexible under certain conditions. The two different materials in my sculptures are meant to represent the difference between male and female, which are determined by our

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[5] The website can be found on http://www2.ntu.ac.uk/dnaseonghee

[6] Hydrogen bond: week bond in which a hydrogen atom is shared by 2 toher atoms, an important bond in many large biological molecules in stabilising secondary and tertiary structure and in the binding of substrate to enzyme.(Eleanor Lawrence ed., Henderson's dictionary of biological terms 11th ed.,1995)

[7] Covalent bond: a form of chemical bonding that is characterized by the *sharing* of pairs of electrons between atoms. In short, attraction-to-repulsion stability that forms between atoms when they share electrons is known as covalent bonding.

[8] Ball-and-stick models are 3D or spatial molecular models which serve to display the structure of chemical products and substances or biomolecules.

DNA. Scientists' visualisation using the ball-and-stick model is unable to show the difference in character between men and women in the structure of DNA.

7.2.2 GM (DNA modification) and GM (Genetic modification)

Lynn Gamwell, director of the Art Museum at the State University of New York, pointed out that recently many artists have explored questions around applied science or biotechnology (Gamwell 2003). I was concerned about genetic modification (GM) technology because my husband Dr Kim was working on a GM research project at Nottingham University from 1997 to 2004, in which he introduced DNA recombination techniques.

Since the 1970s, genetic engineering has dramatically developed. At present, many genetically modified products such as rice and corn are sold in markets. These genetically modified products are made by DNA recombination techniques that introduce and remove target genes on original genes using cutting by restriction enzyme and insertion by DNA ligase.

To express DNA recombination techniques as an artist, I used the ideas of cutting and ligation (familiar to molecular biologists) to shape my sculptures (shown in figure 37 and 38). The two different styles of helix – the cubic and the round shape – are heterogeneous, not homogeneous. They are intended to show the diverse characteristics of DNA and to make the audience think about the many implications of this new science which has potential implications for the future of human life. The previous sculptures were meant to highlight the organic nature of DNA, whereas these sculptures focus on the unnatural character of genetic modification technology, which is represented by the cubic strand of the helix. However, I did not want to break away from the natural beauty inherent in the DNA double-helix. When I make these works, I always think about the contrast and harmony between nature and technology, art and science, male and female, life and death.

7.2.3 DNA Sea Shell

As a basic unit or element of living organisms, DNA can be found everywhere. In this sculpture, I explored the similarity between DNA structure and a natural creature, in particular, sea shell. I think it is worth noting again that similarity and ubiquity can explain why the double helix has become a prevailing cultural icon.

Sea shells are commonly found on beaches, but also in the form of fossils that can be used for studying periods of natural history that predate human life on earth. I would like to describe the beauty of sea shells as a metaphor for genetic information passed from generation to generation. My *DNA Sea Shell* (Figure39) sculpture explores these themes through the structure of DNA as a spiral shape in nature.

Whilst looking for examples of spiral shapes in nature, I found a book called *Curve of Life* (1979) by Theodore Andrea Cook, who was an English writer, editor and Olympic swordsman. He also wrote another book called *Spirals in Nature and Art* (1903) which includes a great number of spiral forms, both organic and artificial. Martin Kemp (2006) pointed out that a central thesis in Cook's book is that the logarithmic spiral characteristic of shells and phyllotaxis[9] was associated with the designs of nature and art:

> **For Cook, the true artist or architect assumed a special role in the revelation of the central truths of natural design, since the insightful artist's perceptual system was 'of a more sensitive fibre' than that of ordinary mortals (Kemp 2006 p. 205).**

In 1982, D.S. Fensom wrote a review of *Curve of Life* in the art journal *Leonardo*. He explained that Cook discovered beauty in the spirals of living things after he had come upon a spiral staircase at the Royal Palace of Blois. He wrote:

[9] The arrangement of leaves on a plant stem.

> **Good Art, like Life, suggests T. A. Cook, is that which possesses curves, usually spirals, never quite mathematically perfect, yet exquisitely combining function with form. (Fensom 1982)**

Artists, including me, have been moved or inspired by deeply-underlying natural laws. Especially with the development of technology, we are able to know that the structure of DNA has a spiral form. I believe that artists interested in nature should attempt to reflect the laws of structure and growth exemplified throughout organic life.

I chose to use wood to make this sculpture of a seashell because the annual growth rings that are present in wood are also to be found in sea shells. The wood was coloured with blues and greens (sea colours) and it was also coloured by burning with a blow-torch, in order to represent the passage of time during the shell's life under water.

7.2.4 DNA Connection

In this sculpture (Figure 40), I used two different colours of stone: one was creamy limestone, the other was a black-stone, to contrast between each helix and to represent sperm and egg or man and woman. I carved each stone into a helix and put them both together to form a double helix. The sculpture was inspired by the process of fertilisation, in which each germ cell such as sperm and egg is fused and DNA recombination occurs. Originally, sperm and egg have half the genetic material (or information) compared to other somatic cells. Thus through fertilisation, the chromosomes share genetic material with each other and together they combine to form a whole chromosome again. This event is the beginning of living things and continuity of life. I would like to articulate the biological connection of people through this conception of DNA.

7.2.5 DNA Tombstone

All living things are mortal; their DNA lives on after death. *DNA Tombstone* (Figure 41) explores this aspect of life. All living cells produce protein for maintaining life processes. To do this, DNA is wrapped around histones[10], into a ball-shaped octamer structure, which have to be unravelled to transcribe genetic information. In my sculpture, I explored this process of unravelling packed DNA in the transcription event in order to reflect the mortal and immortal aspects of life. It is ironic that DNA is the basic unit of organisms that will pass away someday, and yet these mortal and temporary beings can hand down their genetic material in a continuing process. In this way, *DNA Tombstone* reflects this duality of life.

Richard Dawkins observes the relationship between the body and genes in his book *The Selfish Gene* (1989):

> **The genes are the immortals, or rather, they are defined as genetic entities that come close to deserving the title. We, the individual survival machines in the world, can expect to live a few more decades. But the genes in the world have an expectation of life that must be measured not in decades but in thousands and millions of years … They march on. That is their business. They are the replicators, and we their survival machines. When we have served our purpose we are cast aside. But genes are denizens of geological time: genes are forever (Dawkins 1989, p. 34-35).**

In this section, I have given an account of the seven sculptures shown in the *DNA Structure and Human Desire* exhibition. Its main purpose was to explore the DNA structure and to reflect my personal view of the post-genomic era and the iconic nature of my subject. I do not aim to merely replicate the images of DNA but to interpret the double helix through abstract objects.

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[10] Histone: any one of a set of simple basic proteins rich in arginine and lysine, bound to DNA in eukaryote chromosomes to form nucleosomes (Eleanor Lawrence ed., Henderson's dictionary of biological terms 11th ed.,1995)

Figure 35 *DNA Endless Desire* (Seonghee Kim, 2003, Ash, 100x25x25cm)

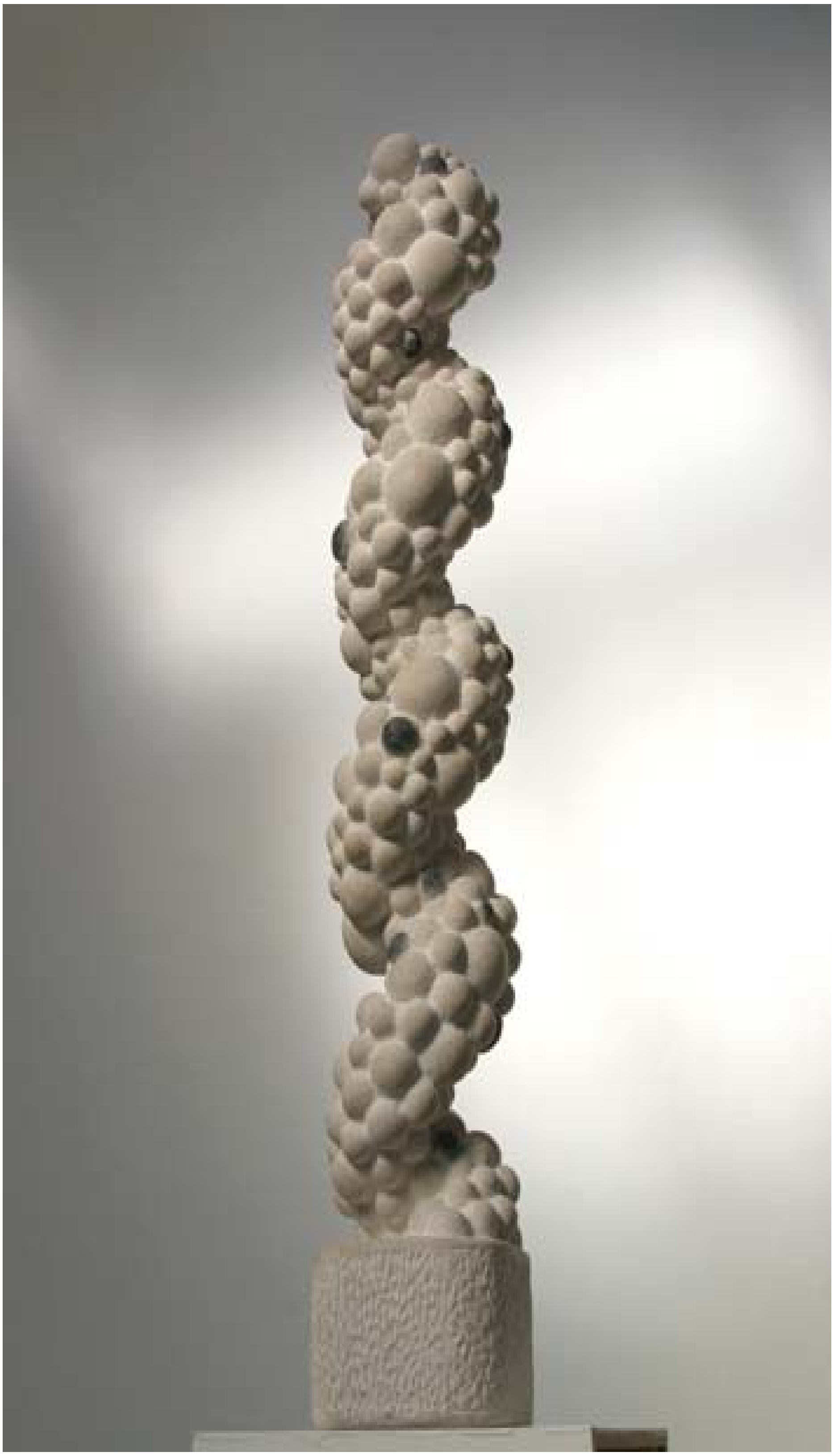


Figure 36 *DNA Endless* (2004). (Seonghee Kim, 2004, Limestone, 100x17x17cm)

Figure 37 *DNA Modification* (Seonghee Kim, 2004, Limestone, 150x25x25cm)

Figure 38 ***GM (Genetic modification)*** (Seonghee Kim, 2003, Ash, 100x17x17cm)

Figure 39 *DNA Seashell* (Seonghee Kim, 2004, Ash, 120x30x30cm)

Figure 40 ***DNA Connection***
(Seonghee Kim, 2004, Limestone and Black-stone, 120x15x15cm)

Figure 41 ***DNA Tombstone*** (Seonghee Kim, 2004, Mix, 200x40x10cm)

7.3 The Adventure of the Double Helix

This exhibition was inspired by scientists' drawings from the 2003 conference at Cold Spring Harbor Laboratory, which was described in chapter 3. The drawings showed the scientists' concepts of DNA, and were displayed on the website of the science journal Nature[11]. I was surprised by the variety of visualisations, and my curiosity about the scientists and their research was the inspiration and starting-point for my exhibition *The Adventure of the Double Helix.*

The exhibition opened in Biocity, Nottingham, from 18th-24th September, 2005. It was sponsored by Art and Business, Biocity, Bionex, and Nottingham Trent University. The exhibition included drawings of concepts of DNA by artists, scientists and other professionals, together with my copper relief and artworks and carvings. The exhibition was an attempt to communicate with the public different understandings of the conception and visualisation of DNA structure.

In collecting the ten works for the exhibition, I found that both scientists and artists use diagrams and drawings as part of their research processes in order to visualise their conceived ideas and to communicate the concepts with the public. I am interested in how scientists use diagrams in their research and how artists visualise their ideas through drawing. The exhibition reveals that both diagrams and drawings are vehicles to transfer or develop thoughts from the imagination to an end product.

I investigated the idea that imagination is essential to the process of interpretation by conducting an experiment: I asked artists, scientists and other experts in their field to express their thoughts about DNA using drawing in order to analyse the relationship between their drawings and their knowledge of the concept of DNA. The drawings are illustrated in Figure 42-44.

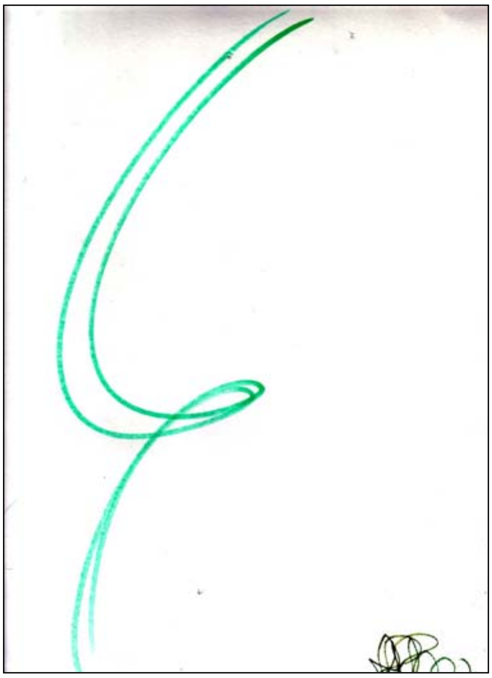
What I found from their drawings is that their own area of expertise was reflected in their drawing, for instance, Professor Keith Campbell, who cloned

[11] http://www.nature.com/nature/dna50/gallery

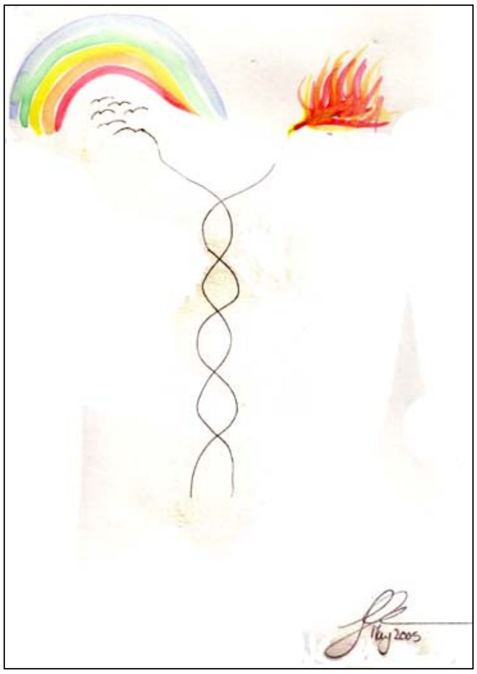
Dolly the Sheep, drew a sheep with twisted lines reminiscent of the DNA helix. Sound artist Andrew Brown produced a quick line drawing of the helix which suggested the fluidity of sound.

I interpreted the drawings in a new artwork, a relief on copper sheets which were mounted onto sheets of mahogany (Figure 45-46). The drawings were transferred to the copper which was then shaped using the pointing technique. After the copper was attached to the mahogany, the wood dried over time and began to warp, which changed the shape of the copper. This was an unintentional effect, but the end result added to the appeal of the polished copper surfaces. The reliefs were shown with other pieces of my work in the Biocity exhibition, which is concerned with the exploration of DNA and with people's perceptions of the building blocks of life.

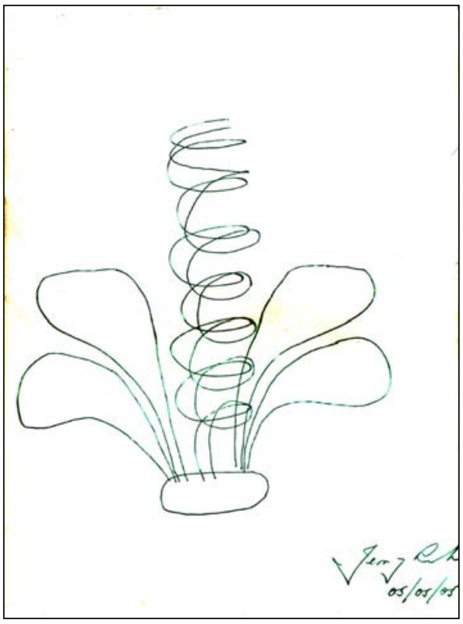
I chose the Biocity science business space as the location for this exhibition because, unlike a dedicated art gallery space, it provides an opportunity for people to see my work in a real-life situation. This exhibition was partly sponsored by the Art and Business organisation, and in 2005 they selected me to receive the 'New Partnership' award, which is given to the best artists who have worked with a company or business.



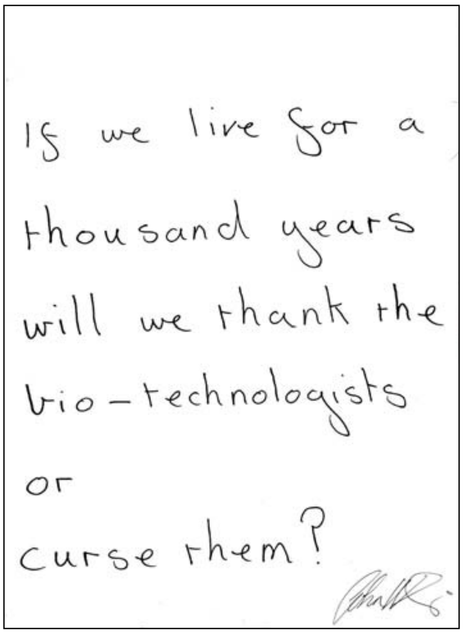
Andrew Brown
Sonic Artist
Nottingham Trent University



Dr. Glenn Crocker
Chief Executive
Biocity

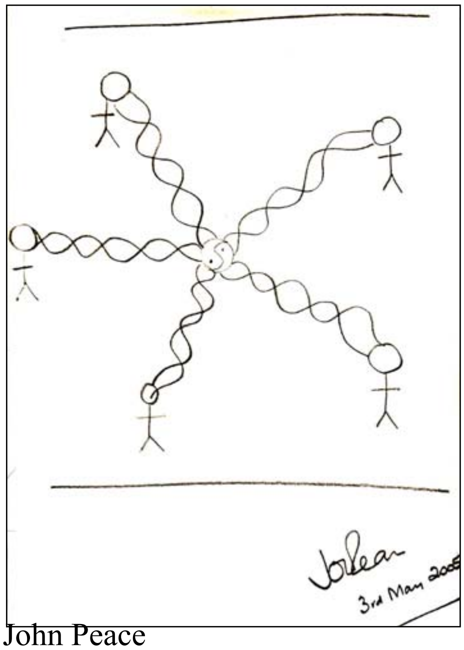


Professor Jerry Robert
Head of Plant Sciences Division
The University of Nottingham

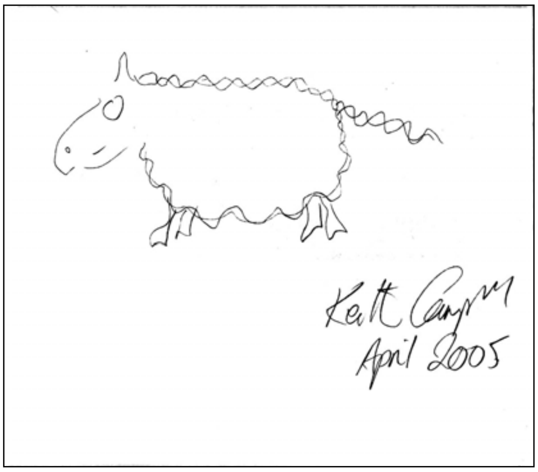


Professor John Newling
Artist, Professor of Art &Design
Nottingham Trent University

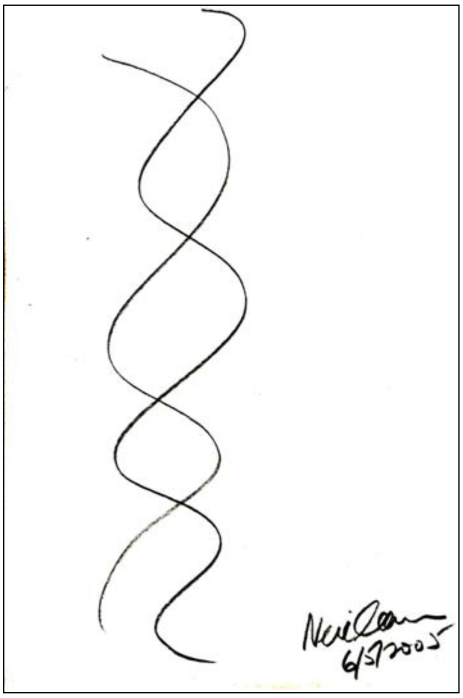
Figure 42 Drawings of concepts of DNA for the exhibition *The Adventure of the Double Helix.*



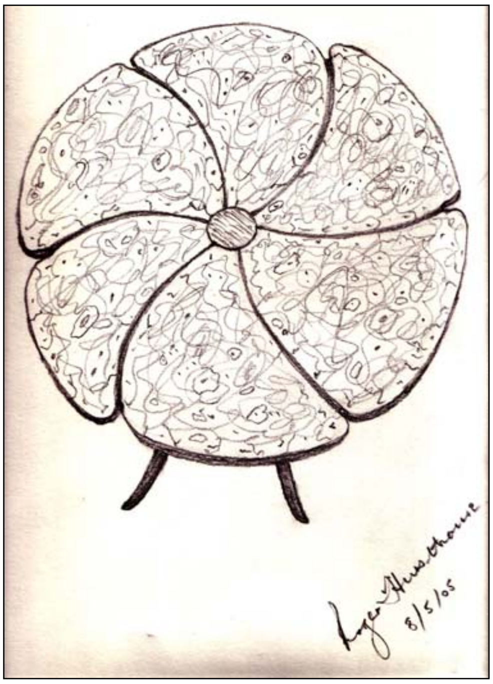
John Peace
Chairman of the Board of Governors,
Nottingham Trent University
Group Chief Executive, GUS plc



Professor Keith H S Campbell
Division of Animal physiology
The University of Nottingham

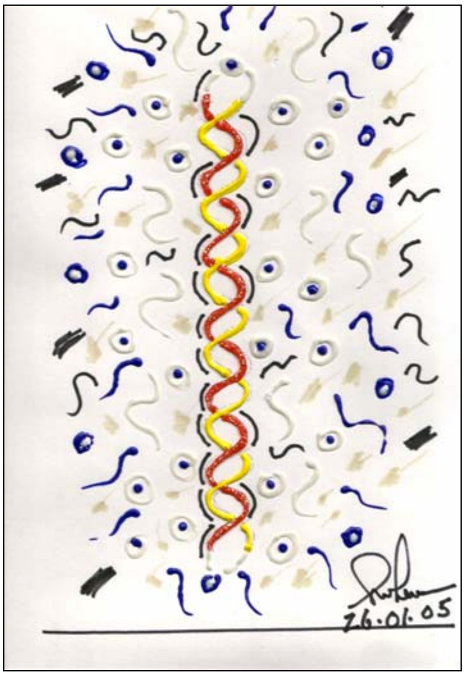


Professor Neil Gorman
Vice chancellor
Nottingham Trent University



Roger Hursthouse
Governor, New College
Nottingham
Director of Three Score Ltd

Figure 43 More drawings for *The Adventure of the Double Helix*



Professor Simon Lewis
Head of Art & Design and
the Built Environment,
Nottingham Trent University

Dr. Steve Beasley
Chief Executive of East Midlands
Bioscience Exchange

Figure 44 More drawings for *The Adventure of the Double Helix*

Figure 45 Drawing by John Peace and relief based on the drawing.

Figure 46 Relief based on these drawings

7.4 Life is Endless Desire

A Sci-Art exhibition entitled *Life is Endless Desire* was displayed as part of the Korean Science Festival 2005 from 12th to 21st August 2005 in Daejon, South Korea, and was supported by Korea Science Foundation (KSF), the British Council in Korea, and Nottingham Trent University.

During my PhD research, I entered a Sci-Art project to the Korea Science Festival 2005 organized by KSF. The purpose of the project was to collaborate with the scientist Professor Keith Campbell, and to demonstrate how artworks exploring DNA can evoke meaningful speculation about the relationships between art and science. My proposal was accepted by the Korea Science Foundation and exhibited at the festival.

In 1996, Dolly the sheep was created, not by normal fertilisation (fusion of egg and sperm), but by a team of scientists led by Dr. Ian Wilmut and Keith Campbell who cloned her from the cell of an adult sheep. They injected the cell into a sheep egg from which they had removed the nucleus, replaced the egg into the mother and left it to develop naturally. Their technique could bring about the possibility of human cloning. But the true power of cloning will be realised when it is combined with genomics and genetic engineering. It truly opens up the possibility of designer animals and babies and potentially gives us control over living systems.

These developments have inspired the work in my exhibition *Life is Endless Desire*, which comprises two test-tubes – a small one contained by a larger one. The larger tube is like the cellular membrane, and the smaller is like the nucleus. Inside the tubes stands a stone helix, like DNA inside the nucleus. Written in the stone are sequences of the letters A, T, C, G, which denote the base components of DNA. The complex genetic characteristics of every living thing can be written in sequences of these letters. It is reminiscent of the biblical book of Genesis, where ‘In the beginning was the word’. Words are essential to human explanations of life, so too are forms and colours. Geneticists can also map out sequences of A, T, C, G, by giving a colour value to each letter.

Anthony Crabbe, a lecturer at Nottingham Trent University, described my work in the exhibition catalogue as having a deep understanding of nature versus nurture:

> **Seong-Hee looks at the extent to which experience is a defining feature of what we call individuality. However alike human clones may be, if they have fundamentally different life experiences, we should expect them to have quite different personalities that will contribute quite differently to society overall. In other words, our lives may still be driven more by our thoughts and sentiments than by genetic algorithms. These ideas raise the traditional debate about nature and nurture, which confronts every parent of a child that carries their genes and their hopes (Kim 2005).**

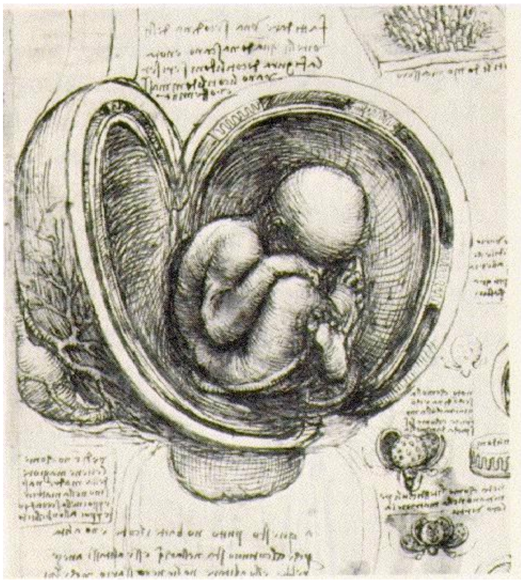
The exhibition included works by me and my brother, SeongHeon Kim, a ceramicist from Korea and myself. As can be seen in figure 52, around the central sculpture are masks that are very similar, but not the same. SeongHeon Kim made hundreds of masks by casting his face. In his mask works, he explored the idea that cloned animals are not absolutely the same; even clones are individuals.

The exhibition focused on the DNA structure model in terms of positive attitude towards genetic engineering amongst the general public. This installation addresses the question of social and cultural issues of genetic engineering and animal cloning. I collaborated with Keith Campbell, professor of the University of Nottingham, who produced 'Dolly the sheep', and Anthony Crabbe. Campbell accepted my offer to collaborate on my Sci-Art project for the Korean Science Festival. I visited his laboratory and his PhD students, and was shown details of cloning techniques, and how to spell words using a DNA codon program (explained in detail below). From conversations with Campbell, I learned that cloned animals are not actually identical; this idea highlighted the role of nurture as opposed to nature, which informs the themes in my artwork.

We gave several lectures to them at the exhibition on, a science TV programme by KBS and some formal lectures at Korean universities. I believe these communications allow people to consider art and science as one unit of knowledge and understanding of human nature. Before this exhibition, Sci-Art as we know it in the West was unknown in the Korean culture. The phrase ‘Sci-Art’ was used, but it referred to computer and internet-based art; it was associated with technology as opposed to science. Anthony Crabbe introduced *Life is Endless Desire* at the Sci-Art exhibition.

One image which gave me inspiration to build my art work *Life is Endless Desire* was Leonardo da Vinci’s famous drawing of a foetus in the womb (Figure 47 a). When I looked at this picture, I imagined that if he knew about DNA at his time, he would have used DNA to make his artwork. Martin Kemp mentioned that the da Vinci drawing is a miracle of intense presentation and is replete with visual analogies of a microcosmic kind (Kemp 2000). Kemp also said that the womb is clearly not that of a human mother: the image of the womb has been adapted from the beautiful drawing da Vinci made of his dissection of the gravid uterus of a cow (Kemp 2000).

When I saw *Foetus in the Womb* and *Foetus in the Womb of a Cow* by da Vinci (Figure 47a), I imagined a DNA structure in the womb instead of a human figure. I imagined the womb as a cell (Figure 47 b), which inspired the main artwork in the exhibition.



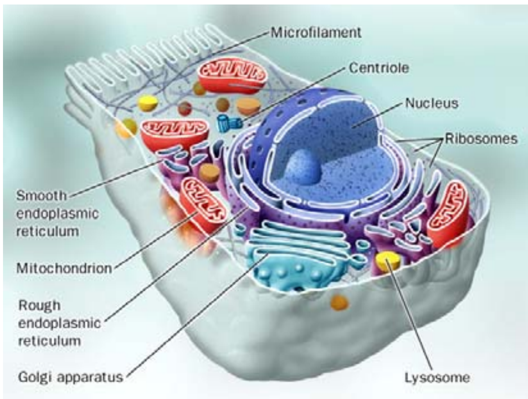


Figure 47a Foetus drawing by Leonardo da Vinci and **47b** Cellular structure

I used the DNA codon as my theme. Basically, amino acids[12] are encoded by three nucleotides, which are called a codon. For example, the sequence ATG codes for the amino acid Methionine. The amino acid can be shown as the three-letter abbreviation 'Met' or as the one-letter abbreviation 'M'. Using this process (Figure 48), this sequence of codons

"TTA ATA TTC GAA ATA TCA GAA AAC GAC TTG GAG TCC AGC GAT GAA TCA ATA CGA GAA" translates into the title 'LIFE IS ENDLESS DESIRE'

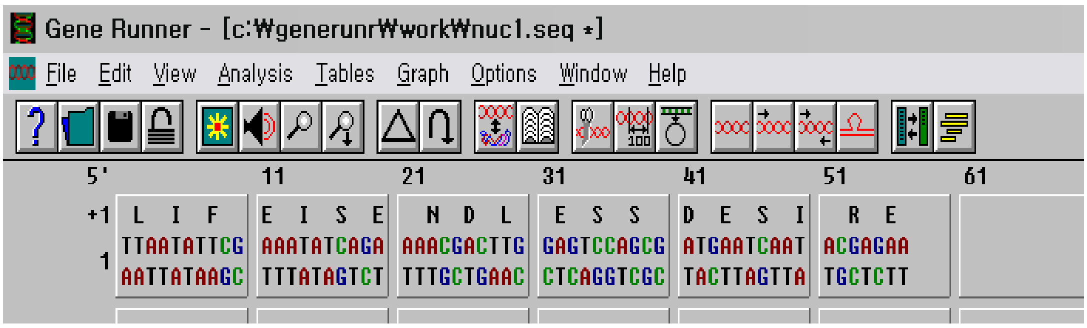


Figure 48 ***Translation of genetic code with one-letter abbreviations.***

There are only 22 letters used to represent 22 different amino acids, so there are 4 letters – J,O,U and X – which are not used. The four bases A, T, G, and C make all living things from unicellular organisms to humans. This exhibition

[12] Very small unit of living organisms; proteins consist of many amino acids.

aimed to express the human desire to seek something, whether invisible or visible, because scientists and artists have an endless curiosity with nature. I intended to show human nature as having endless desire.

Richard Dawkins claims in his book, *The Selfish Gene* (Dawkins 1989), that the genes formed by our DNA are structured solely to reproduce themselves at any cost. In this sense, our genes appear to have an even more ruthless desire to succeed than our own personalities. Before Dolly and the Genome Project, we only had relatively limited powers over the processes of reproduction. But now, by learning to write in a new language – the DNA code – we have greater potential control over such genetic processes. This power also comes with great responsibility (see discussion on eugenics in chapter 3).

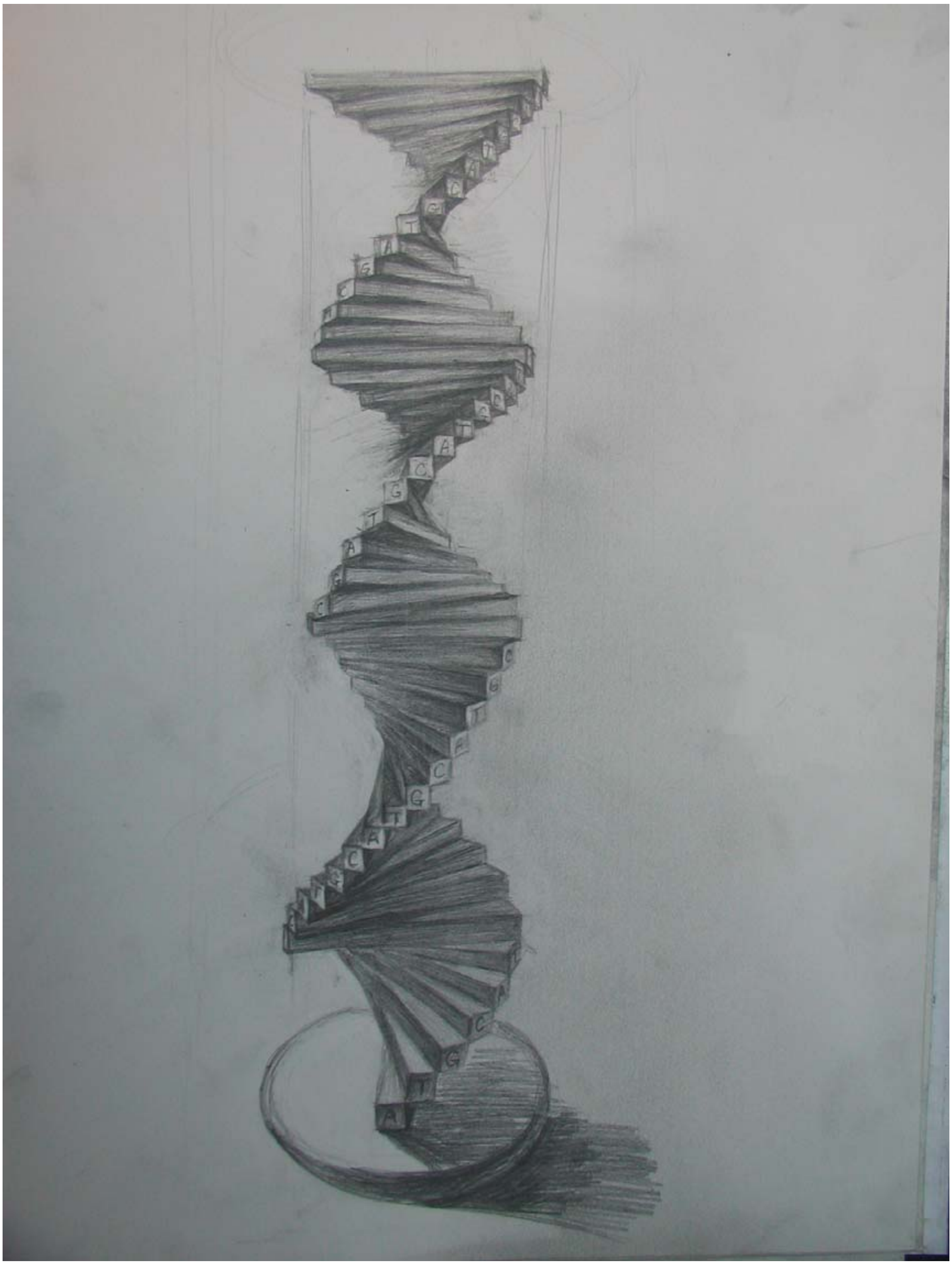


Figure 49 Idea sketches for *Life is Endless Desire* exhibition

Figure 50 Idea sketches for *Life is Endless Desire* exhibition.

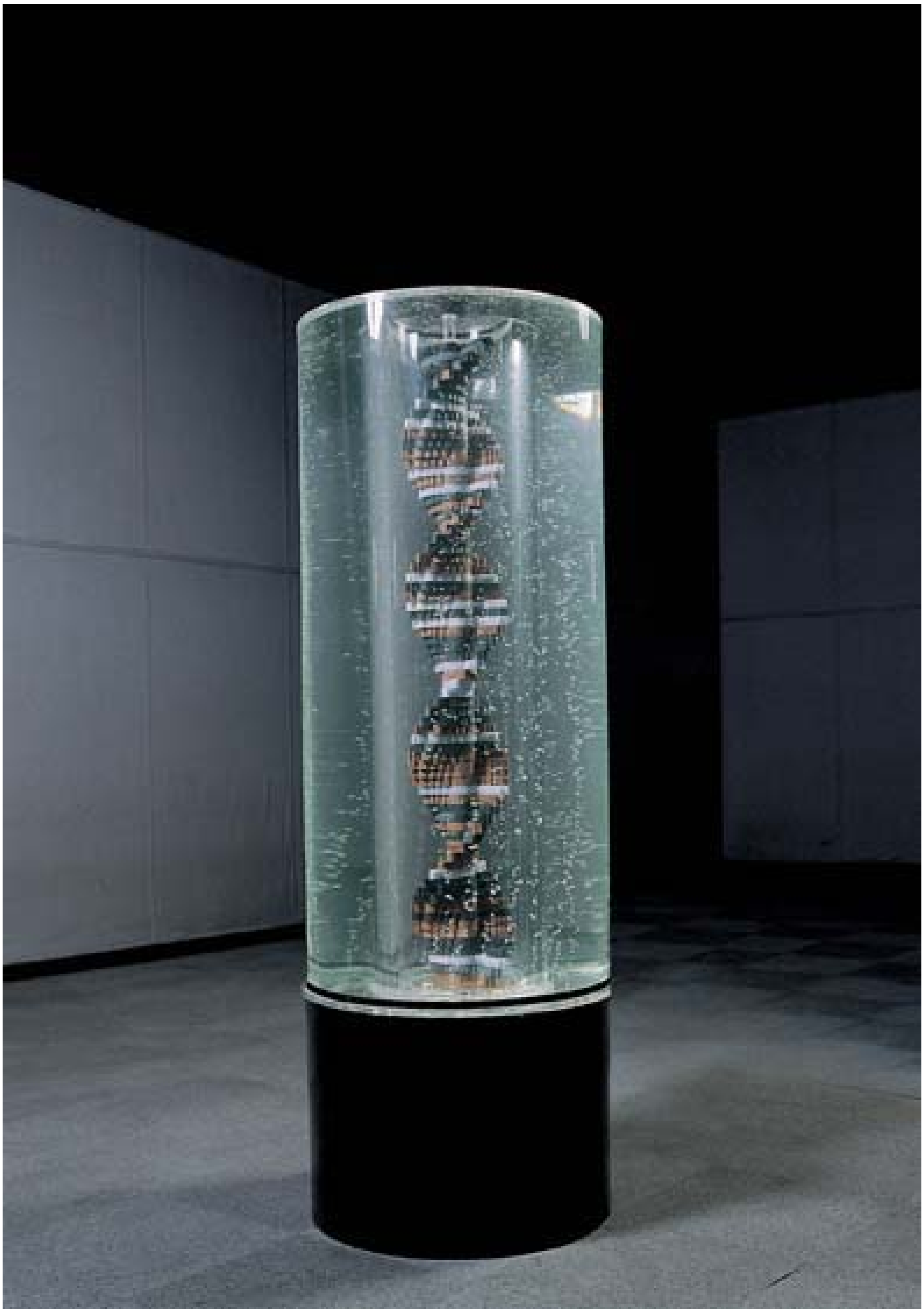


Figure 51 The part of installation "TTA ATA TTC GAA ATA TCA GAA AAC GAC TTG GAG TCC AGC GAT GAA TCA ATA CGA GAA"

Figure 52 ***Life is Endless Desire***
Exhibited as part of the Korean Science Festival 2005 from 12th to 21st August 2005 in Daejon, South Korea.

7.5 *ART: Visual artists from the UK*

ART, an exhibition of artists' work from Nottingham Trent University was exhibited at the Art Centre of Chunag-Ang University, South Korea as part of a cultural exchange program with Nottingham Trent University, and was sponsored by both universities. It was a group exhibition of artworks by fine artists from the School of Art and Design at Nottingham Trent University.

My work in this exhibition was an installation exploring the theme of 'endless DNA' using a form of fractal. The term 'fractal' was coined by Benoit Mandelbrot in 1975, and referred to self-similar objects such as clouds, coastlines and plants (Mandelbrot 1982). The study of fractals was greatly developed by Mandelbrot, which later became an important subject in science and mathematics. A fractal as a geometric object has a fine structure, irregular shape, self-similarity, and a simple and recursive definition. In addition, they are frequently considered to be infinitely complex due to similarity at all levels of magnification (Falconer 2003). Fractal patterns can be found in the leaves in trees, the veins in a hand, or the DNA molecule which is a double helix and repeating as well as self-assembling. DNA assembles individual living creatures into larger structures.

In the exhibition, I installed two aquariums each containing a sculpture and fish, located on opposite sides of the room (figure 54-55). Using one camera located behind each of the sculptures, repetitive images of DNA structure were transferred by projectors onto a screen that was positioned in the middle of the two installations. Finally the screen showed two different DNA structures being overlapped and repeated. DNA is not to be seen only as a chemical structure, but also as a character that has a specific role within individual lives. Through the shape of DNA structure in the aquarium where it coexists with live fish, I attempted to express the beauty of DNA structure as a part of nature and as a theme of life.

In this installation, I tried to show DNA as an irregular and repetitive shape to represent its intrinsic attributes. The structure of DNA shown in *Nature* (Figure 53b) is an 'ideal' image when compared to a picture of the structure revealed by scanning tunnelling microscope (STM)[13] (Figure 53a). As Rhonda Roland Shearer indicated, the STM image of DNA represents a direct imitation of nature, echoing nature's irregularities, whilst Odile Crick's DNA diagram can be seen as an antagonist of nature, an abstraction and idealisation transcending nature's imperfections (Shearer 1996).

Scientists such as Eugene Stanely, a physicist at Boston University, Wentian Li of the Rockefeller University and Richard F. Voss of the EMB Thomas J. Waston Research Centre, discovered scale-invariant fractal patterns in the large-scale positions and seqeuencing of DNA's four nucleotides (Yam 1992 and Amato 1992). In this sense, my artwork displayed fractal-like images of DNA structure, and expressed the complexity of nature as irregular and repetitive but at the same time having order in the complexity. I think these are significant attributes of nature, which are echoed and renewed in my installation.

[13] The scanning tunneling microscope (STM) is a non-optical microscope that scans an electrical probe over a surface to be imaged to detect a weak electric current flowing between the tip and the surface.

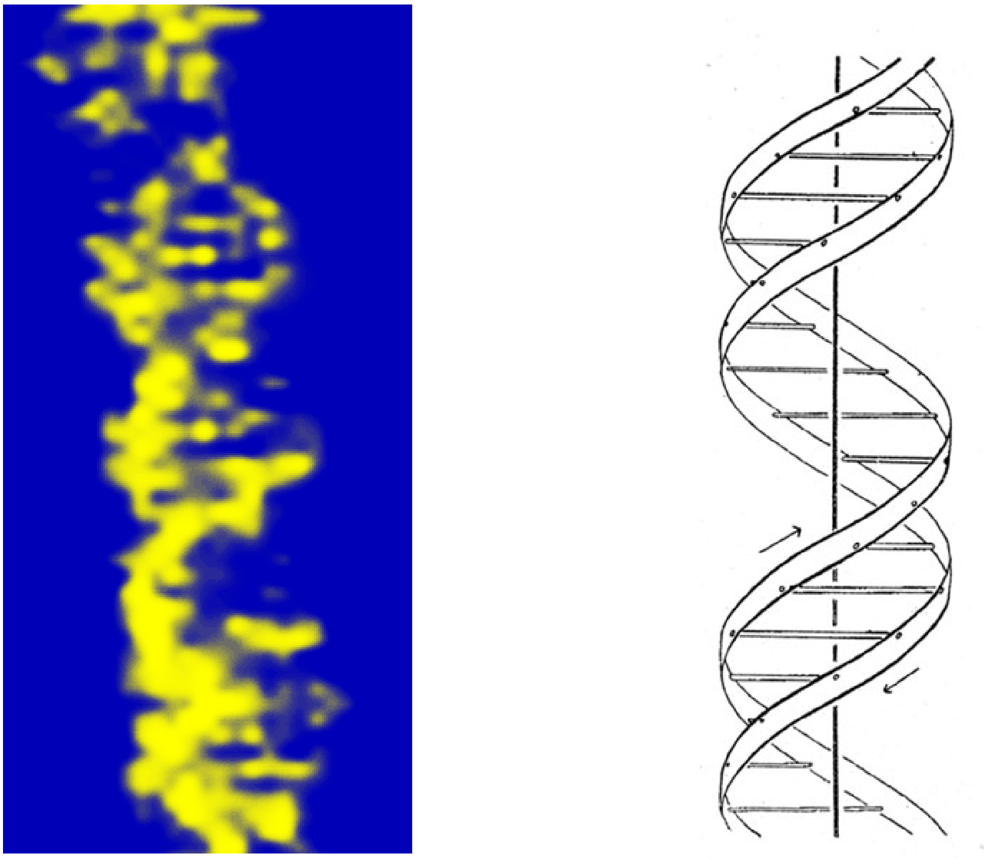


Figure 53a STM image of DNA structure[14] and Figure **53b** Odile's DNA drawing[15]

[14] http://www-aix-old.gsi.de/~bio/RESEARCH/PICTURES/dna1.gif
[15] http://www.nature.com/nature/journal/v421/n6921/fig_tab/nature01403_F2.html#figure-title

Figure 54 Installation at *Art* exhibition

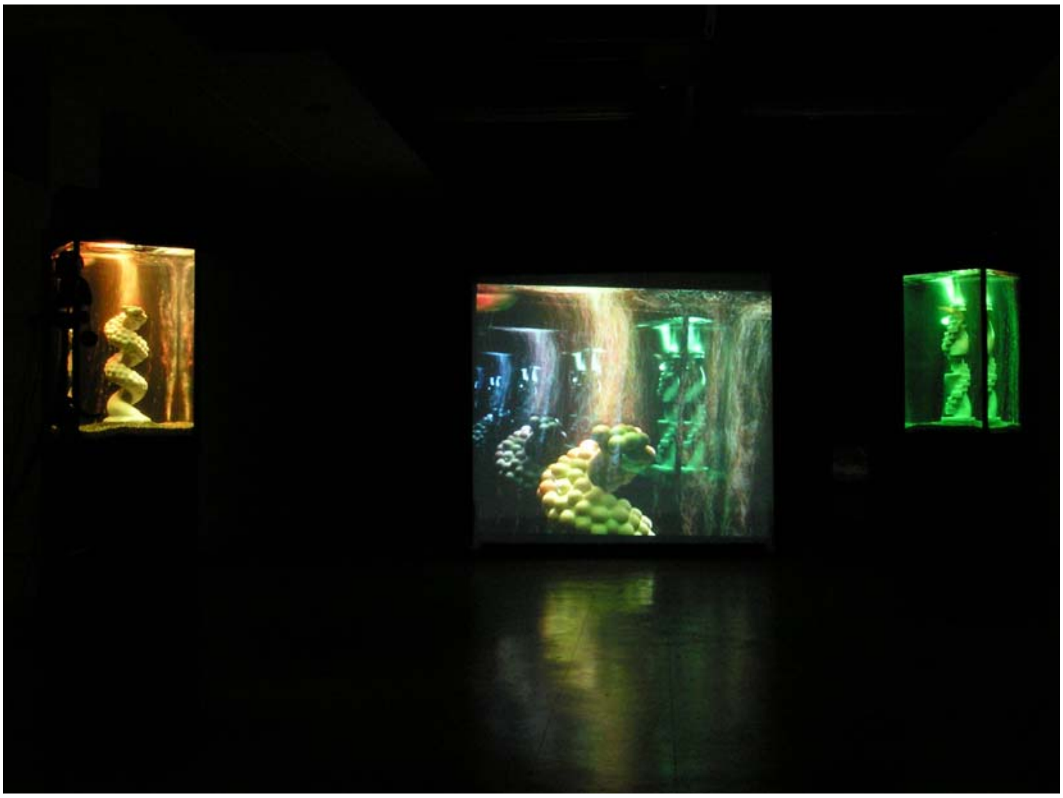


Figure 54 Installation at *Art* exhibition

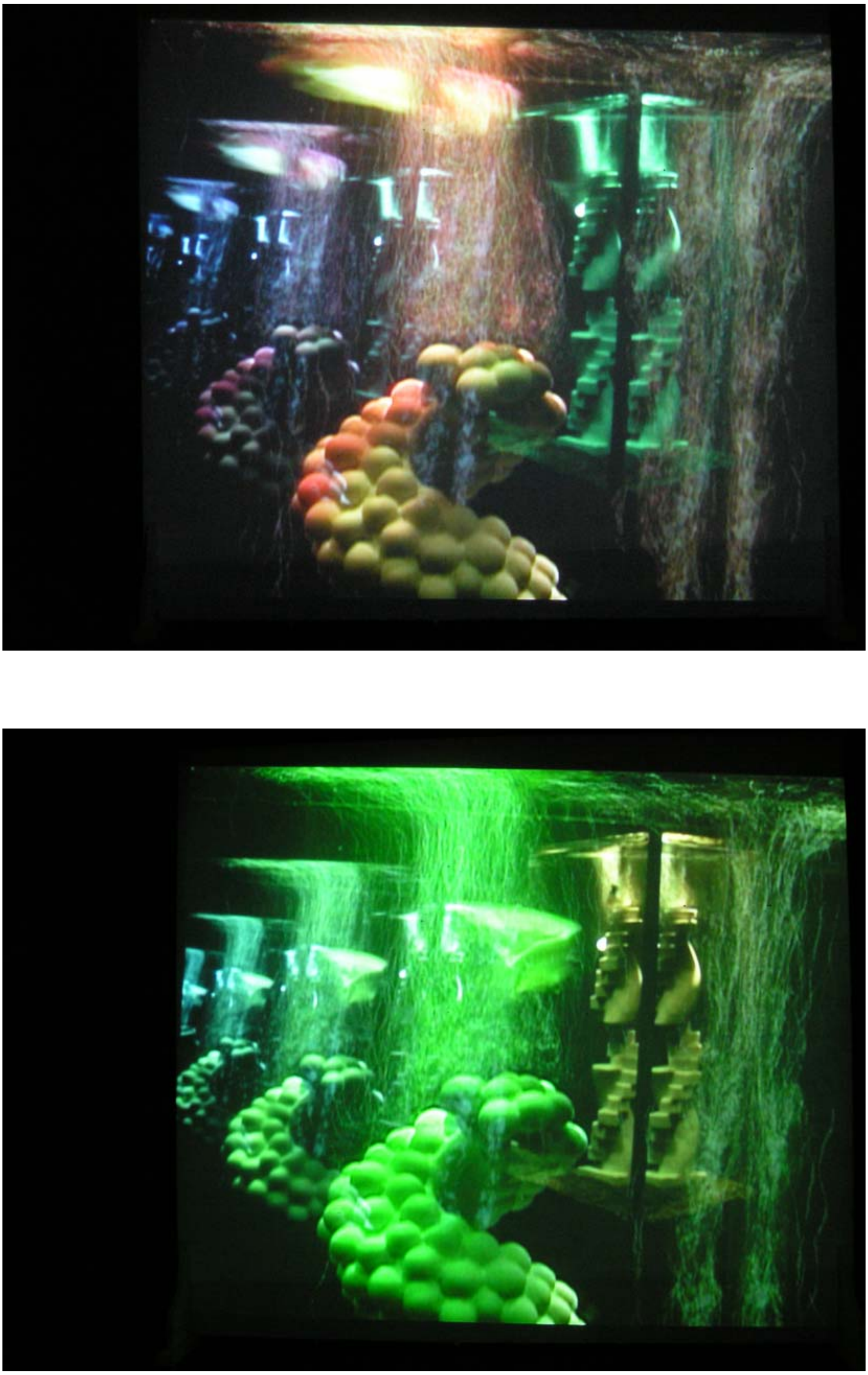


Figure 55 Installed sculpture of DNA structure in aquarium and reproduced images on screen.

7. 6 *Laboratory*

I was involved with another Sci-Art project, *Laboratory*, which was performed at Trinity Catholic School, Leamington Spa, England from 5th Feb. 2007 – 19th Feb. 2007. I worked as a resident artist, and produced several art works with students at key stage 3 (11 – 12 years old).

In this installation, I intended to represent DNA with natural materials and items normally used in a laboratory. To do this, we needed to understand the structure of DNA and discuss and review the meaning of DNA for our artworks. Firstly, I showed the beautiful double helix structure, and how the structure can be constructed from scientific and artistic view points. Secondly, we discussed he theme of the installation. DNA is widely used for personal identification, and in this respect, the installation explored personal identification in terms of DNA structure.

I attempted to explore the relationship of nature and science in this project. It was important to define the significant attributes of nature, even though every day we are a part of nature. When I started the project, it was autumn and some trees had begun to change the colour of their leaves: some were still green, and as time passed, most of the trees lost their leaves, which then covered the ground. We also looked at artificial materials, laboratory items such as test tube, Pasteur pipettes, and culture dishes, which allowed us to become familiar with science and technology (Figure 56).

In this installation, I created double helices with students. One helix made of fallen leaves was a metaphorical expression of the cycles of life, growth and death that are found in nature. Another helix was made of long acrylic tubes used in science laboratories. These tubes were a metaphorical expression of the ways that biotechnology research has touched our life and has raised moral and social issues in our society (Figure 57a-b).

The main purpose of this project has been to explore the structure of DNA and to reinterpret the conception of DNA with students.

Figure 56 Installation ***Laboratory***

Figure 57a Part of installation 'Laboratory' **57b** Students making installation

7.7 Conclusions

The first theme of my work was concerned with aesthetic viewpoints of DNA structure and scientific understanding. This was further developed in the second theme which explored what DNA means to people and how they visualise this conception. Finally, I attempted to collaborate with scientists and students to communicate through art and science. Through these themes, I found that my artworks are influenced by the sum of all my knowledge, study and experience. I believe that artwork is a powerful tool for touching our emotion and opening new thought. My work does not need verbal explanations, and does not have only one correct interpretation. I have tried to make artworks with all my imagination and knowledge to visualize a variety of themes.

These sculptures and exhibitions are the final outcome of my research based on practice, and they also related to the chapters of this thesis as the following table shows:

Table 5 The relation between exhibitions, themes and chapters

Artworks/Exhibitions	Purposes	Chapters
DNA Structure and Human Desire 2004 *Art* 2006	Representation of the double helix structure	Chapter2: DNA structure Chapter3: DNA as cultural icon
The Adventure of Helix 2005	Understanding and visualisation of DNA structure	Chapter4: Visualization DNA structure by scientists Chapter5: Visualization DNA by artists
Endless Human Desire 2005 *Laboratory* 2007	Collaborative work for education and public communication	Chapter6: Collaboration between art and science in education Chapter 7: Interdisciplinary Collaboration

People have responded to my works in a positive way: many of my works have been bought by various individuals and institutions. The table below lists all my work that has been purchased for exhibition in science communities and educational organizations:

Table 6 Purchase of my sculptures from science communities and educational organizations

Date of purchase	Sculpture Title	Location
2005- permanent	DNA Endless	BioCity, Nottingham, U.K
2005- permanent	DNA Connection	BioCity, Nottingham, U.K
2005- permanent	DNA Tombstone	Bonnington Building, Nottingham Trent University, U.K.
2005- 31/12/2007	Endless Human Desire	Korean Research Institute of Bioscience and Biotechnology, Korea
2007-07-16 permanent	Desire	Trinity Catholic School, Warwickshire, U.K.
2007-07-16 permanent	Chromosome	Trinity Catholic School, Warwickshire, U.K.

I develop scientific elements using my knowledge and imagination to make sculptures. The artworks are exhibited in galleries, science communities and public spaces, and the audience are scientists, students and the public. My creative process could be likened to the embryonic development from fertilisation to foetus in Figure 58. The egg represents my artistic practice, and the sperm represents science, which includes its images, texts, people and practices.

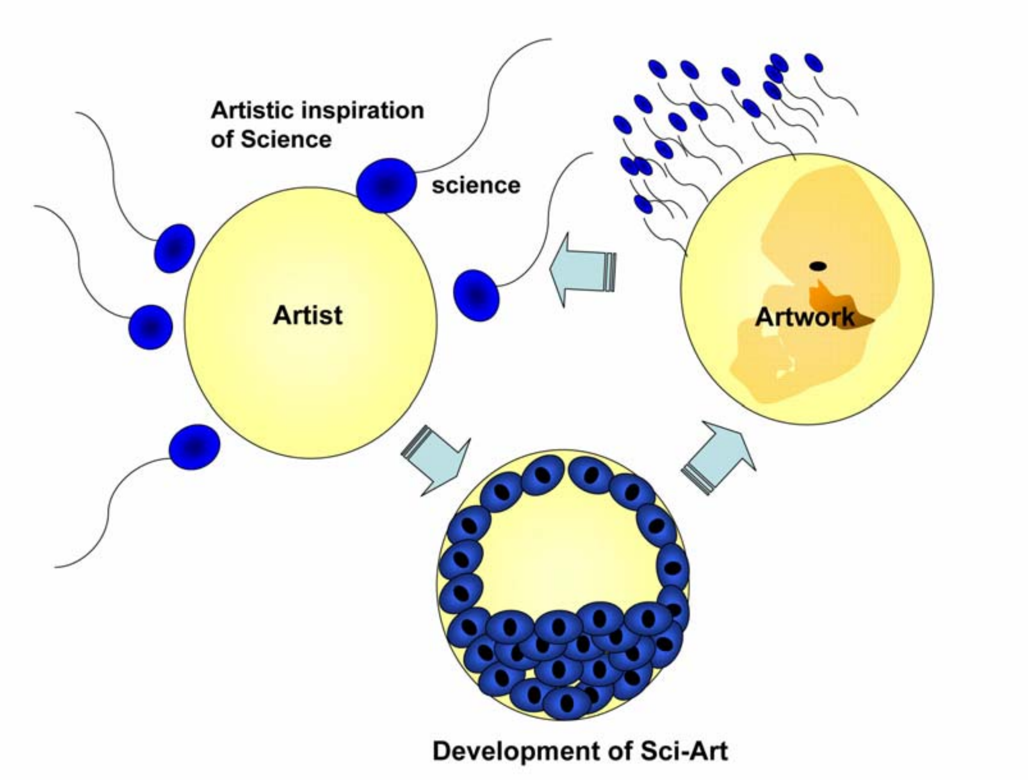


Figure 58 Developmental processes of my art.

Art and science have important positions in our cultural contexts. However, when they meet and function as a unit of knowledge like a foetus, they can inspire each other and produce new things that never existed before. I believe that my artworks presented in this chapter are a step toward a richer and more inclusive understanding of the relationship between science and art. I would like to continue to develop artwork showing the relationship between art and science.

Chapter 8

Conclusion

8. 0 Thesis conclusion and further research questions

The success of biotechnology has changed our expectations of how long we might live, and how we can deal with problems like disease and food supply. Biotechnology expanded in the 1970s, but began with Watson and Crick's discovery of DNA structure in 1953. Biomedical and genetic research has progressed by using knowledge from the technology of DNA. Since 1990, an increasing number of artists have been inspired by biotechnology and the social and moral issues that surround it. Sci-Art is the name given to this artwork that uses scientific concepts, images or technology. It has been argued that Sci-Art takes from science without giving back. My argument is that Sci-Art makes contributions to society by:

- Acting as an aid to understanding difficult scientific concepts
- Adding to debate about the ethical issues surrounding science
- Increasing the effectiveness of education

Relating to each of these issues, my research questions were:

- What are the differences and shared approaches in the visualization of DNA and biotechnology by artists and scientists?
- Why has the DNA structure become a cultural icon?
- What is the role of Sci-Art in contemporary society?

Each chapter of this thesis contributes to answering the research questions: Chapter 1 defined art and science, discussed the similarity and differences between art and science. It also discussed arguments of the benefits to each other, and ended with an evaluation of the benefits of Sci-Art collaboration.

Chapter 2 explored the process of scientific discovery, focusing on Watson and Crick's discovery of DNA structure, and the ways in which they visualised it.

There were two important points: one is that visual imagery contributed to many important steps in the discovery of DNA structure. These include X-ray diffraction photographs by Franklin, which gave Watson and Crick clues about the double helix structure of DNA, and cardboard cut-outs by Watson, which helped solve the problem of matching base pairs. Also, metal models of DNA structure by Watson and Crick confirmed that their theory of the double helix was correct. This chapter argues that imagination and knowledge are among the most important aspects of scientific research, but that they are often unrecognised as such.

The second significant point is that developments in technology after 1953 have allowed scientists to visualize its structure in a variety of other ways. For example, the new scanning tunnelling microscope (STM) reveals a very different picture of DNA in which its structure is shown to be more irregular and lumpy in reality than in previous visualisations.

Chapter 3 examined DNA as a cultural icon that represents biotechnology and life science. There are three reasons why the double helix has become an icon: Firstly, it is simple and beautiful to depict. Secondly, ideas about DNA as an agent of propagation lead us to explore the origin of all living organisms, and to question identity or individuality. Thirdly, in the globalized and capitalist world, knowledge of DNA and genetics has been applied to agriculture, medicine and the bio-technology industry.

In chapters 4 and 5, I discussed the visualization of DNA by scientists and artists. There are differences and similarities: scientific visualization of DNA structure functions as an indexical sign to explain information about who we are, and is interpreted using analysed data. The interpreted model of DNA structure concisely represents hypotheses or theories, and the structure is comprehended by the scientific community.

The visualisation of DNA by artists is more conceptual. Artists have interpreted DNA as themes of personal identity, monsters, transgenics, eugenics, and commodity. Artists interact with science in three ways: Firstly, they have been inspired by scientific images found in journals and text books. Secondly, they have collaborated with scientists to realise their concepts. Thirdly, they may collaborate with the public or students to make artworks on science subjects and scientific issues, in activities sponsored by institutions and scientific organizations.

Despite these differences between the scientific and artistic use of the DNA icon, there are similarities too: art and science both involve creativity and imagination, because they both need visualizations of their concept to communicate with the public.

In chapter 6, I argued for the importance of collaboration between art and science in education. Questionnaires about Sci-Art were carried out with students from Trinity Catholic School. These two-part questionnaires were designed to explore: 1) the question as to how students regard science and art, and 2) their attitudes towards Sci-Art. The results from the questionnaires are significant for analysing the gap between art and science because they supported Sci-Art as beneficial to education.

As technology has developed such tools as microscopes and electronic computers, science subjects have become more complicated and specialized. It becomes more problematic to communicate with the public and students, who may have difficulties understanding science subjects. Compared with science, students think that art subjects are interesting and not so difficult. The results showed that understanding of art and science by students was poor, but attitudes towards Sci-Art were very positive. It indicates that Sci-Art could be a bridge between art and science if from an early age students have more opportunities to study the relationship between the two different disciplines.

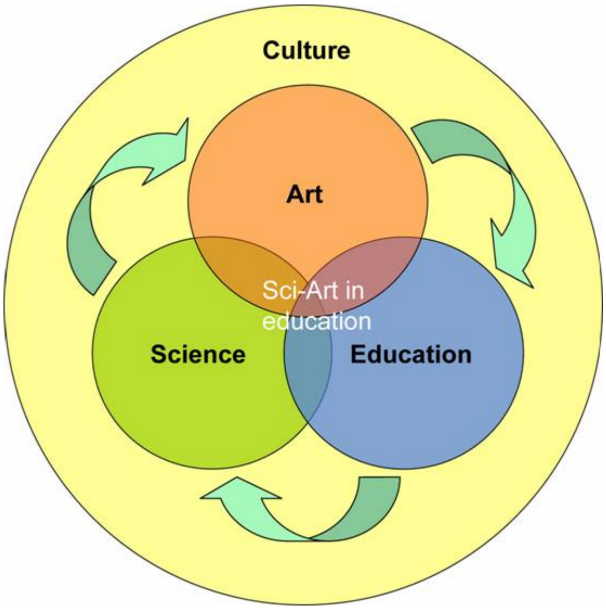


Figure 59 Benefit of collaboration of science and art in education

One role of Sci-Art is that it allows the public to understand complicated science and technology more easily by illustrating or simplifying concepts, and by raising social issues to inform what happens now or will happen later. As shown in figure 59, science, art, and education are intersecting cultural domains. Sci-Art projects can be adopted as a new bridging discipline in education to improve communication between art and science, and help to understand their intrinsic and extrinsic conceptions.

Chapter 7 introduced my own artworks as the outcome of my research. The five objectives of my artwork were as follows:

1. To represent DNA structure as a celebration of nature
2. To aid understanding and visualisation of DNA structure
3. To collaborate with scientists and exhibit for the public
4. To explore the reality of DNA with fractal images
5. To use Sci-Art as an educational tool.

These processes developed in the sequence given above, but they also feedback to and influence one another. The first step was to express aesthetic viewpoints of DNA structure with scientific understanding. This was extended in the second step by exploring what DNA means to people and how they visualised their conception. In the third stage, I understood how scientists' visualisation compares to that of art in the act of communication between scientists and the public. The fourth stage revealed that fractal patterns are as common in nature as DNA itself. The conclusion of the fifth stage is that science and art should be taught at the same time in education.

I believe that nature and nurture are equally important to our cultural identity, and that these two elements that shape our identities are like the two backbones of DNA's double helix (Figure 60). So, with this visual metaphor, Sci-Art is similar to the base-pair connections between the two strands. In this way, Sci-Art bridges the gap between nature and nurture, between scientific knowledge and artistic culture.

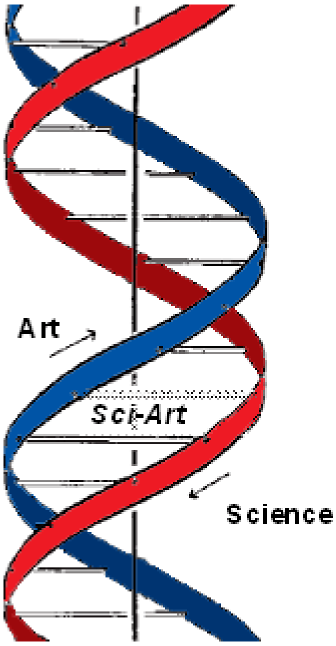


Figure 60 Art and Science as a double helix, based on Odile Crick's drawing of DNA structure that appeared in Crick and Watson's 1953 paper.

I made 20 sculptures and 4 installations during my PhD. This creative activity helped me to understand the relationship between art and science at a deeper level. The exhibitions gave me an opportunity to meet people and talk about the relationship between science and art. Collaborating with scientists in the Korean Science Festival was significant because it strengthened my opinion that Sci-Art can be a bridge between science and public, as illustrated in the figure above.

The feedback I have received and the commissions that I have been offered, demonstrate that my artwork has fulfilled its purpose to stimulate discussion about DNA and the Sci-Art relationship in scientists, the public and students. Many viewers mentioned that my artworks are unique and beautiful, and that they had not thought about DNA in this way before they saw my work. Scientists and scientific communities seemed to like my artworks because it offers a different visualisation to the ones they see and use in their everyday work. As Sci-Art is a new movement in art, people are still unsure about its role, but I believe that my work allows people to understand how Sci-Art can be a powerful tool for communication.

This research lays the foundation for future studies on the benefits of collaboration and how we can fill the gap between science and art, and moreover, which methodological approaches are needed in educational systems. During my PhD research course, I have been involved in sculpture projects with a science museum in South Korea. In further research, I will deploy much of the knowledge that I have gained whilst researching for this PhD. I intend to build on the model of *Sci-Art as a bridge to understanding* that has been developed in this research project. I hope to conduct a case study of the Korean Science Museum, which will explore the research question: what is the influence of artworks on scientific communities and culture? Other possible avenues of research include the question: what are the tendencies of Sci-Art activity in different cultures or countries (for example, comparing U.K and South Korea)?

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Appendices

1, Art and Science questionnaire (Trinity Catholic School)

2, Art and Science questionnaire analysis

AYours Age:

General Questionnaire

1. What do you think about science?
    a. Difficult to understandڤ
    b. Interesting ڤ

c. Not interesting ق
d. Interesting but difficult ق

2. Which areas of science are you most interested in?
   a. Biology ق
   b. Physics ق
   c. Chemistryق
   d. science eromputCق
3. Have you seen the structure of DNA before this class?
   a. Yes ق
   b. No ق
4. When you see the DNA structure, what does the structure remind you?
   a. Double helix ق
   b. Watson and Crick ق
   c. Human genome project ق
   d. Cloning ق
   e. Other, (please describe)

5. What do you think about the structure?
   a. Beautiful ق
   b. Dull ق
   c. Chemical structure ق
   d. Other, (please describe)
6. Do you agree science will improve human life in the future?
   a. strongly agree ق
   b. partially agree ق
   c. neither agree or disagree ق
   d. disagree ق

7. What do you think about art?
   a. Difficult to understandق
   b. Interesting ق
   c. Not interesting ق
   d. Interesting but difficult ق

8. Which kinds of visual arts do you prefer to express your ideas?
   a. Painting ق
   b. Sculpture ق
   c. computing visualization ق
   d. installation ق
   e. if others, (please write down)

9. Do you agree art can help people to understand science?
   a. strongly agree ق
   b. partially agree ق
   c. neither agree or disagree ق
   d. disagree ق
10. After taking this course including express your concepts of DNA with hard paper, which is your opinion about DNA?
    a. still difficult ق
    b. less difficult ق
    c. interesting ق
    d. neither interesting or difficult ق

<u>Questionnaire on specifics of Sci-Art</u>

11. Do you agree science can be new artistic agendas?
    a. strongly agreeق
    b. partially agree ق
    c. neither agree or disagree ق
    d. disagree ق

    (Please briefly express why)

12. Do you agree that collaboration between art and science is necessary and desirable?
    a. strongly agree ڤ
    b. partially agree ڤ
    c. neither agree or disagree ڤ
    d. disagree ڤ

13. Do you agree Sci-Art improves the communication between two different areas?
    a. strongly agree ڤ
    b. partially agree ڤ
    c. neither agree or disagree ڤ
    d. disagree ڤ

14. Do you agree both science and art contribute to the shaping of the future in contemporary society?
    a. strongly agree ڤ
    b. partially agree ڤ
    c. neither agree or disagree ڤ
    d. disagree ڤ

15. Mark A for art, S for Science, and B both in the following elements that represent characteristics of Art or Science, or both

    a. careful observation____
    b. creativity____
    c. use abstract models to understand the world____
    d. aspire to create works that have universal relevance____
    e. seeks aesthetic response____
    f. is of emotion and intuition____
    g visual or sonic communication____
    h. seeks knowledge and understanding ____
    i. is of reason____

Thank you!!!

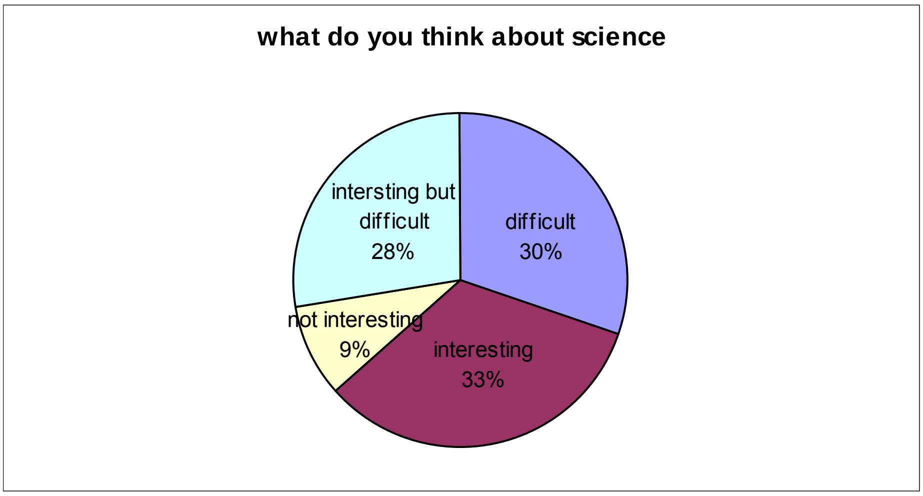
Ethical policy: The information obtained through this questionnaire will be used in my research. No names are required.

a	b	c	d	total
3	5		4	12
3	4	1	2	10
7	6	4	4	21
12	15	6	16	49

	6	4	9	19
25	36	15	35	111

1, what do you think about science

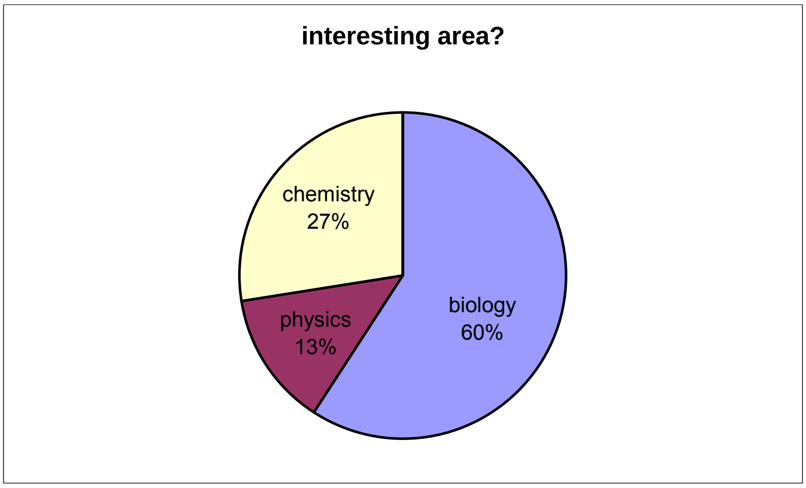
difficult	interesting	not interesting	intersting but difficult
25.00	41.67	0.00	33.33
30.00	40.00	10.00	20.00
33.33	28.57	19.05	19.05
24.49	30.61	12.24	32.65
0.00	31.58	21.05	47.37
22.52	32.43	13.51	31.53



age	a	b	c	d	tatal
11	6	3	3	0	12
12	6	0	3	0	9
14	16	2	5	0	23
15	27	8	13	0	48
16	12	2	7	1	22
total	67	15	31	1	114

2, which areas of science are you most interested?

age	biology	physics	chemistry
11	50.00	25.00	25.00
12	66.67	0.00	33.33
14	69.57	8.70	21.74
15	56.25	16.67	27.08
16	54.55	9.09	31.82
total	58.77	13.16	27.19

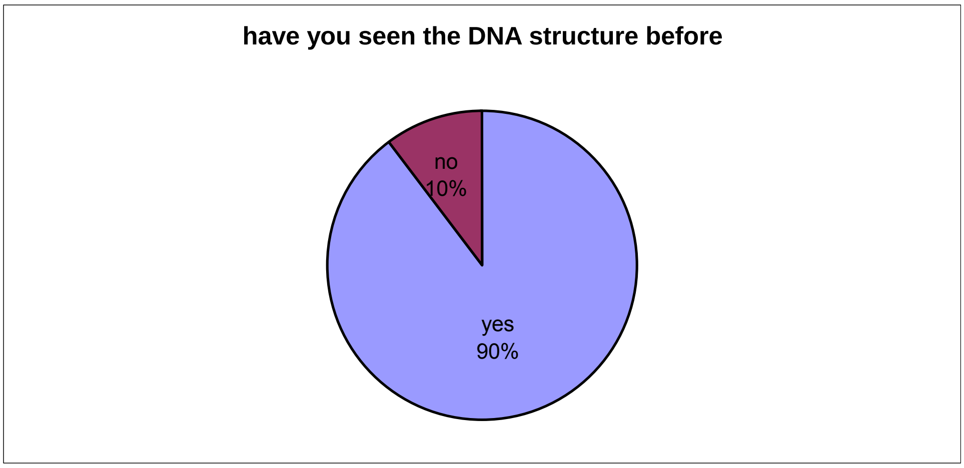


3, Have you seen DNA structure before?

age	yes	no	tatal
11	10	2	12
12	8	2	10
14	19	1	20
15	42	6	48
16	18	0	18

total	97	11	108

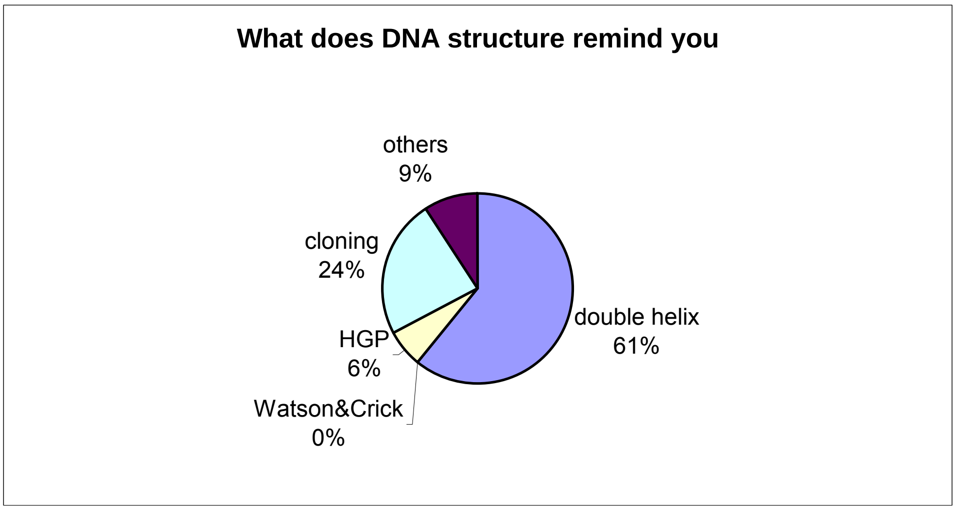
age	yes	no
11	83.33	16.67
12	80.00	20.00
14	95.00	5.00
15	87.50	12.50
16	100.00	0.00
total	89.81	10.19



age	a	b	c	d	e	
11	6	0	0	2	4	12
12	7	0	0	0	3	10
14	15	0	1	7	1	24
15	29	0	6	13	2	50
16	10	0	0	4	0	14
total	67	0	7	26	10	110

4 When you see the DNA structure, what does the structure remind you?

age	double helix	Watson&Crick	HGP	cloning	others
11	50.00	0.00	0.00	16.67	33.33
12	70.00	0.00	0.00	0.00	30.00
14	62.50	0.00	4.17	29.17	4.17
15	58.00	0.00	12.00	26.00	4.00
16	71.43	0.00	0.00	28.57	0.00
total	60.91	0.00	6.36	23.64	9.09

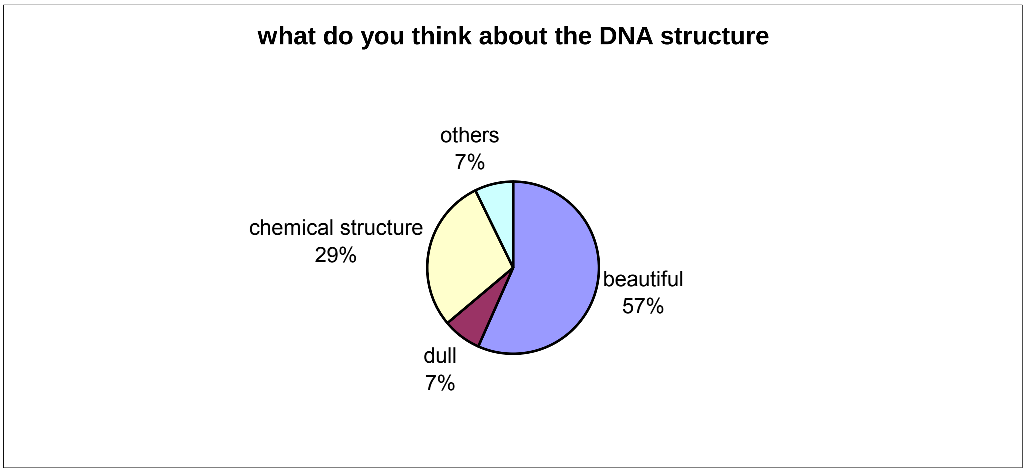


age	a	b	c	d	tatal
11	10	0	2	0	12
12	5	3	2	0	10
14	12	2	5	3	22
15	28	2	14	5	49

16	8	1	9	0	18
total	63	8	32	8	111

5 what do you think about the structure?

age	beautiful	dull	chemical structure	others
11	83.33	0.00	16.67	0.00
12	50.00	30.00	20.00	0.00
14	54.55	9.09	22.73	13.64
15	57.14	4.08	28.57	10.20
16	44.44	5.56	50.00	0.00
total	56.76	7.21	28.83	7.21

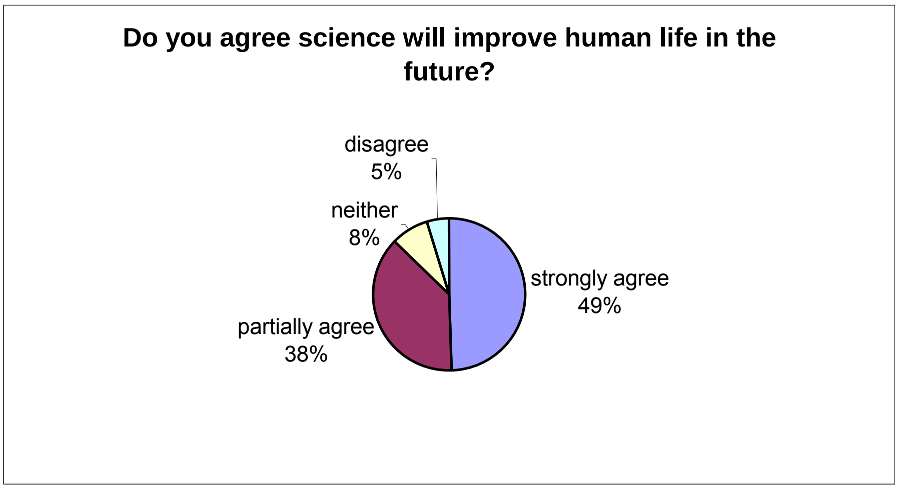


age	a	b	c	d	tatal
11	10	2	0	0	12
12	5	2	2	1	10
14	4	10	5	2	21
15	27	18	2	1	48
16	8	9	0	1	18

total	54	41	9	5	109

6 do you agree science will improve human life in the future?

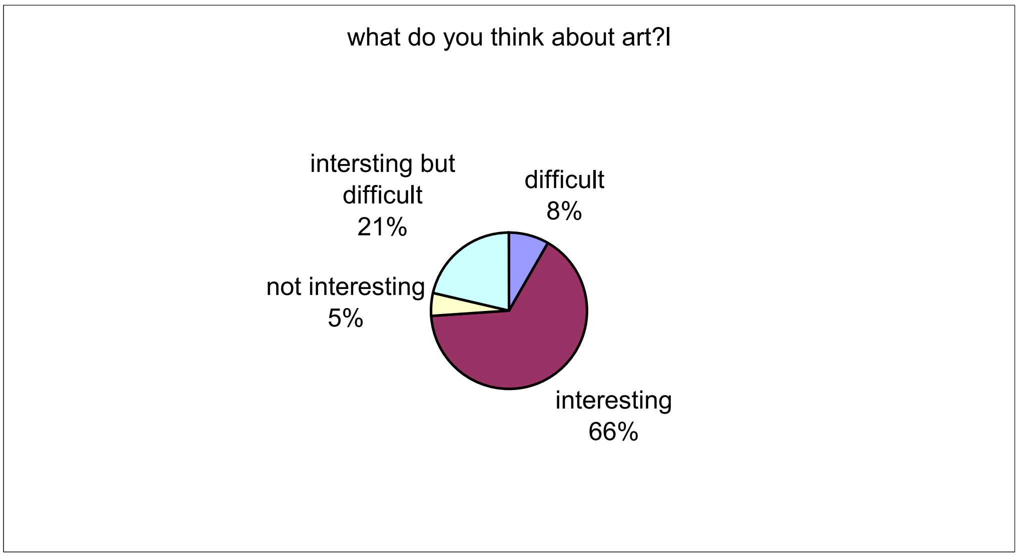
age	strongly agree	partially agree	neither	disagree
11	83.33	16.67	0.00	0.00
12	50.00	20.00	20.00	10.00
14	19.05	47.62	23.81	9.52
15	56.25	37.50	4.17	2.08
16	44.44	50.00	0.00	5.56
total	49.54	37.61	8.26	4.59



age	a	b	c	d	tatal
11	2	7	1	2	12
12	0	7	2	1	10
14	3	12	0	7	22
15	4	33	3	10	50
16	0	11	4	3	18
total	9	70	5	23	112

7 what do you think about art

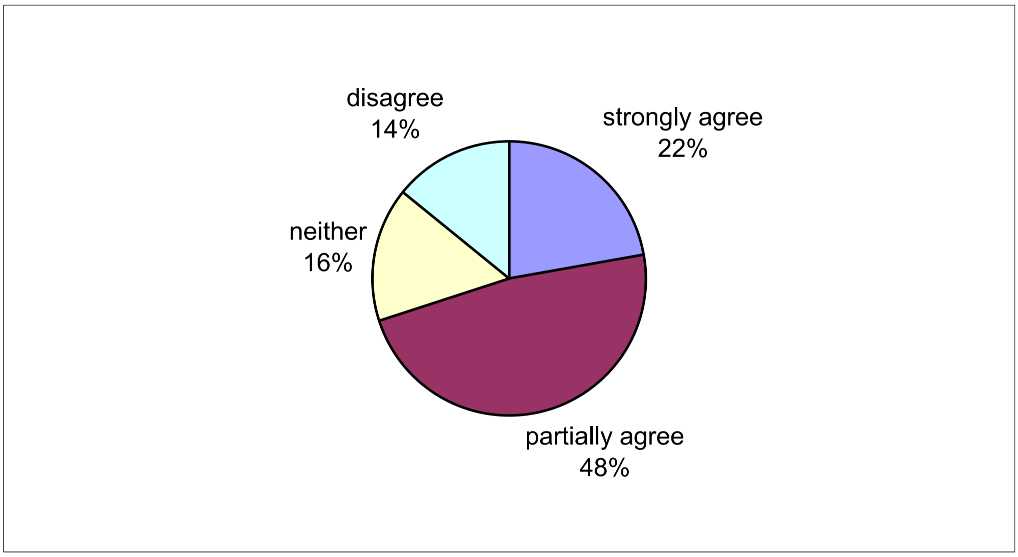
age	difficult	interesting	not interesting	intersting but difficult
11	16.67	58.33	8.33	16.67
12	0.00	70.00	20.00	10.00
14	13.64	54.55	0.00	31.82
15	8.00	66.00	6.00	20.00
16	0.00	61.11	22.22	16.67
total	8.04	62.50	4.46	20.54



age	a	b	c	d	tatal
11	2	6	1	2	11
12	1	5	2	1	9
14	5	13	3	0	21
15	13	26	8	8	55
16	4	4	4	5	17
total	25	54	18	16	113

9 do you agree art can help people to understand science

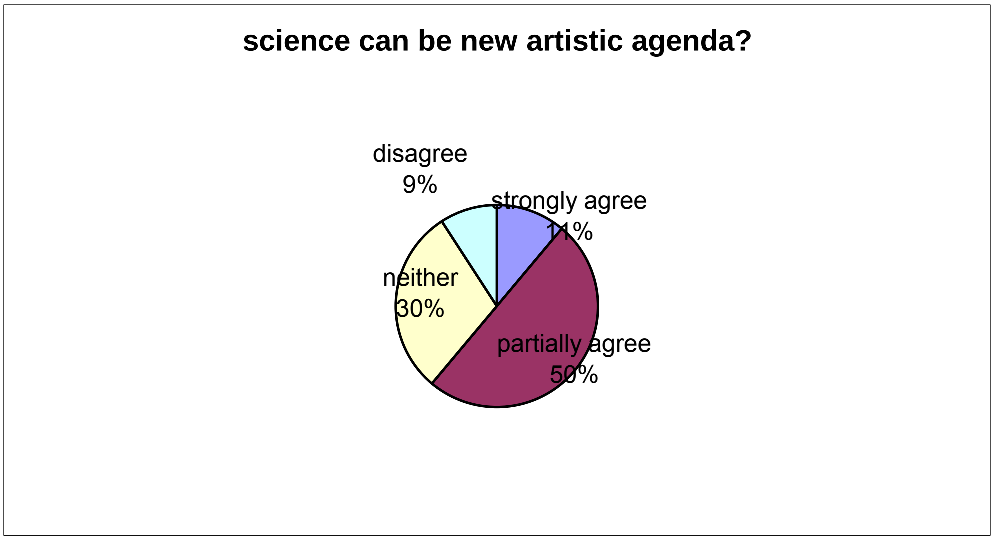
age	strongly agree	partially agree	neither	disagree
11	18.18	54.55	9.09	18.18
12	11.11	55.56	22.22	11.11
14	23.81	61.90	14.29	0.00
15	23.64	47.27	14.55	14.55
16	23.53	23.53	23.53	29.41
total	22.12	47.79	15.93	14.16



age	a	b	c	d	tatal
14	2	5	3	1	11
15	2	13	9	1	25
16	2	9	4	3	18
total	6	27	16	5	54

11 science is new artistic agenda?

age	strongly agree	partially agree	neither	disagree
14	18.18	45.45	27.27	9.09
15	8.00	52.00	36.00	4.00
16	11.11	50.00	22.22	16.67
total	11.11	50.00	29.63	9.26

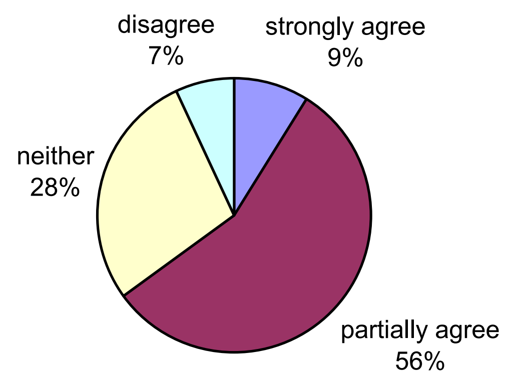


age	a	b	c	d	tatal
14	1	5	3	2	11
15	1	18	9	0	28
16	3	9	4	2	18
total	5	32	16	4	57

12 Do you agree that collaboration between art science is necessary and desirable?

age	strongly agree	partially agree	neither	disagree

age	strongly agree	partially agree	neither	disagree
14	9.09	45.45	27.27	18.18
15	3.57	64.29	32.14	0.00
16	16.67	50.00	22.22	11.11
total	8.77	56.14	28.07	7.02

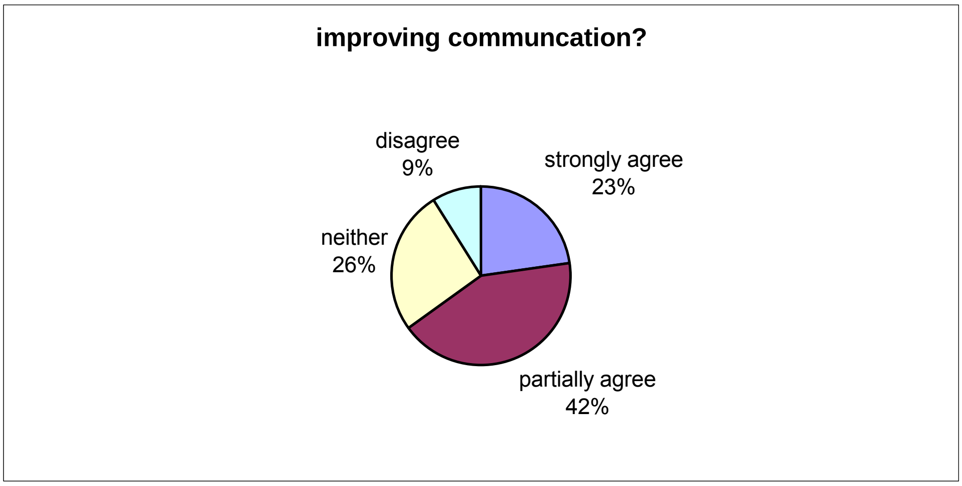


age	a	b	c	d	tatal
14	4	4	2	2	12
15	6	13	8	0	27
16	3	7	5	3	18
total	13	24	15	5	57

13 Sci-art improves the communication b/w science and art

age	strongly agree	partially agree	neither	disagree

age	strongly agree	partially agree	neither	disagree
14	33.33	33.33	16.67	16.67
15	22.22	48.15	29.63	0.00
16	16.67	38.89	27.78	16.67
total	22.81	42.11	26.32	8.77

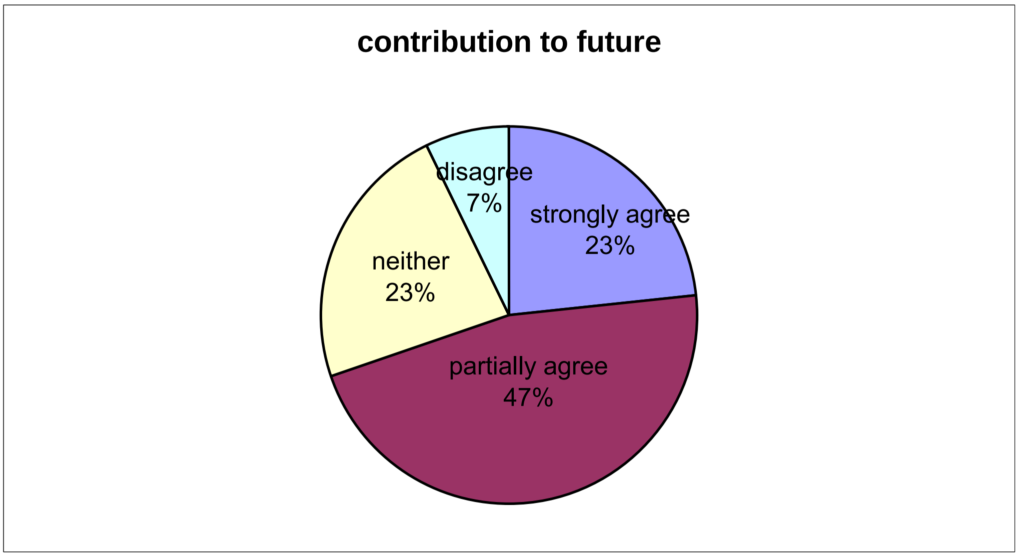


age	a	b	c	d	tatal
14	1	5	3	2	11
15	6	14	7	0	27
16	6	7	3	2	18
total	13	26	13	4	56

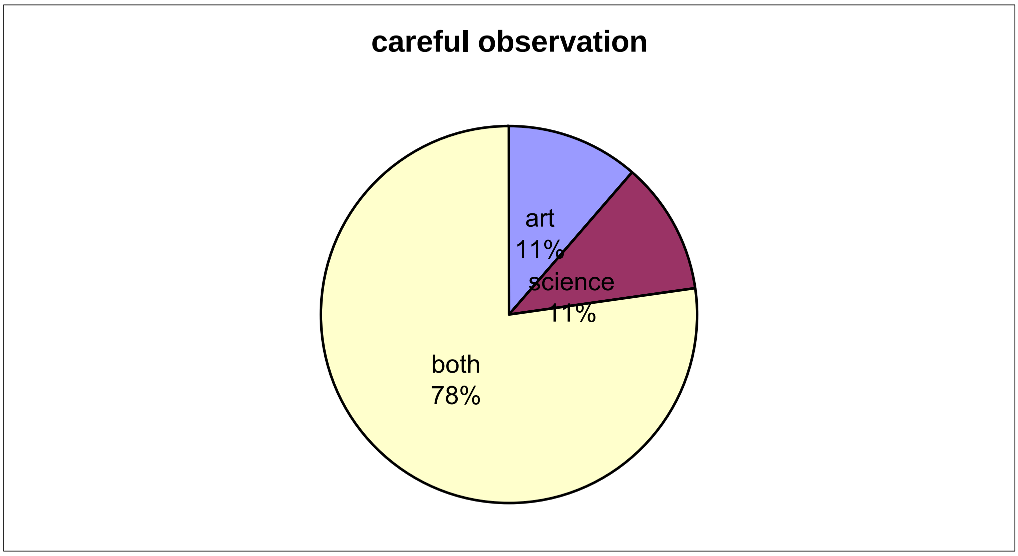
14 contribution to the future

age	strongly agree	partially agree	neither	disagree

age	strongly agree	partially agree	neither	disagree
14	9.09	45.45	27.27	18.18
15	22.22	51.85	25.93	0.00
16	33.33	38.89	16.67	11.11
total	23.21	46.43	23.21	7.14



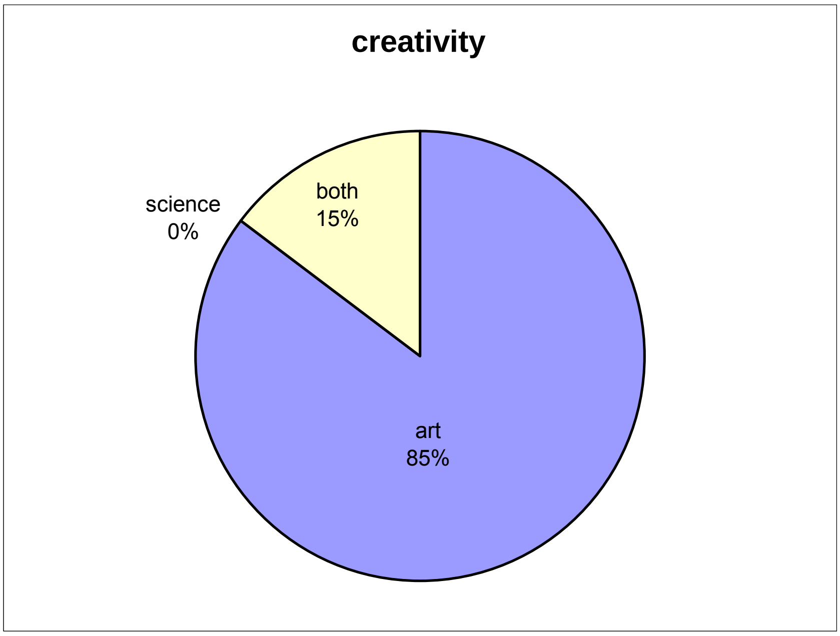
age	art	science	both
14	11.11	22.22	66.67
15	19.23	3.85	76.92
16	0.00	16.67	83.33
total	11.32	11.32	77.36



15-b creativity

age	strongly agree	partially agree	neither
age	art	science	both

14	100.00	0.00	0.00
15	77.78	0.00	22.22
16	88.89	0.00	11.11
total	85.19	0.00	14.81



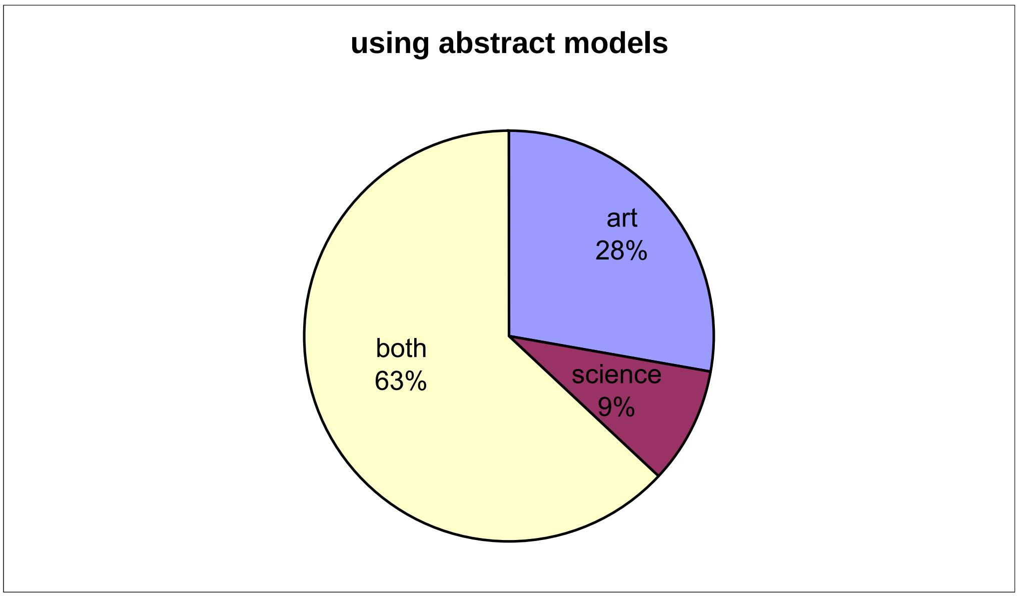
age	art	science	both	tatal
14	6	0	3	9
15	7	2	18	27
16	2	3	13	18

total	15	5	34	54

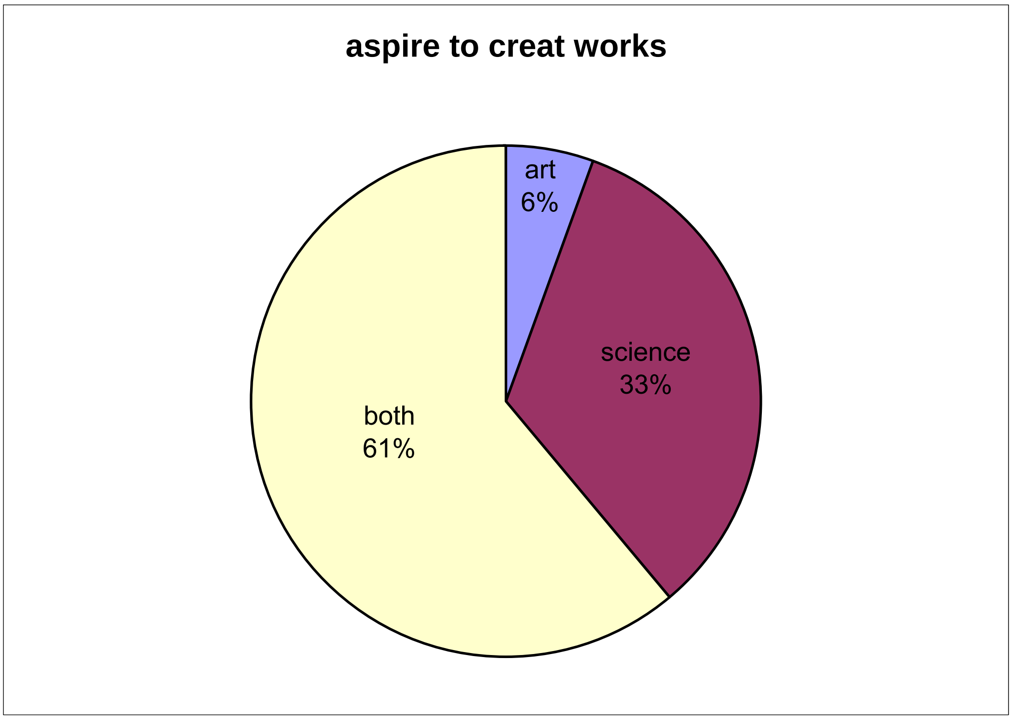
15 using abstract models

age	strongly agree	partially agree	neither

age	art	science	both
14	66.67	0.00	33.33
15	25.93	7.41	66.67
16	11.11	16.67	72.22
total	27.78	9.26	62.96



age	art	science	both
14	22.22	22.22	55.56
15	3.85	34.62	61.54
16	0.00	36.84	63.16
total	5.56	33.33	61.11

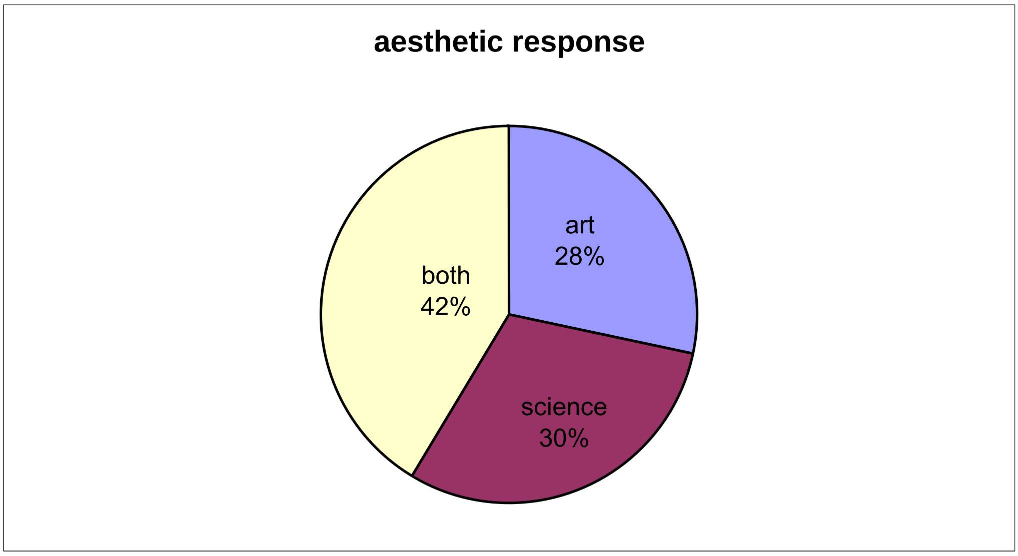


age	art	science	both	tatal
14	2	0	7	9

15	8	11	8	27
16	5	5	7	17
total	15	16	22	53

e seeks aesthtic response

age	strongly agree	partially agree	neither
age	art	science	both
14	22.22	0.00	77.78
15	29.63	40.74	29.63
16	29.41	29.41	41.18
total	28.30	30.19	41.51

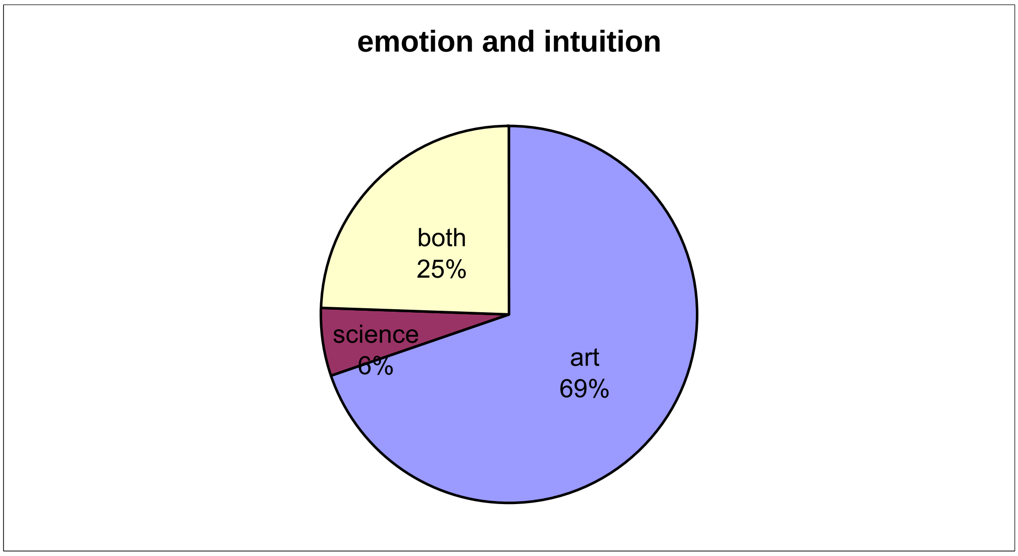


age	art	science	both	tatal
14	8	0	1	9
15	17	2	8	27

16	12	1	4	17
total	37	3	13	53

f emotion and intuition

age	strongly agree	partially agree	neither
age	art	science	both
14	88.89	0.00	11.11
15	62.96	7.41	29.63
16	70.59	5.88	23.53
total	69.81	5.66	24.53



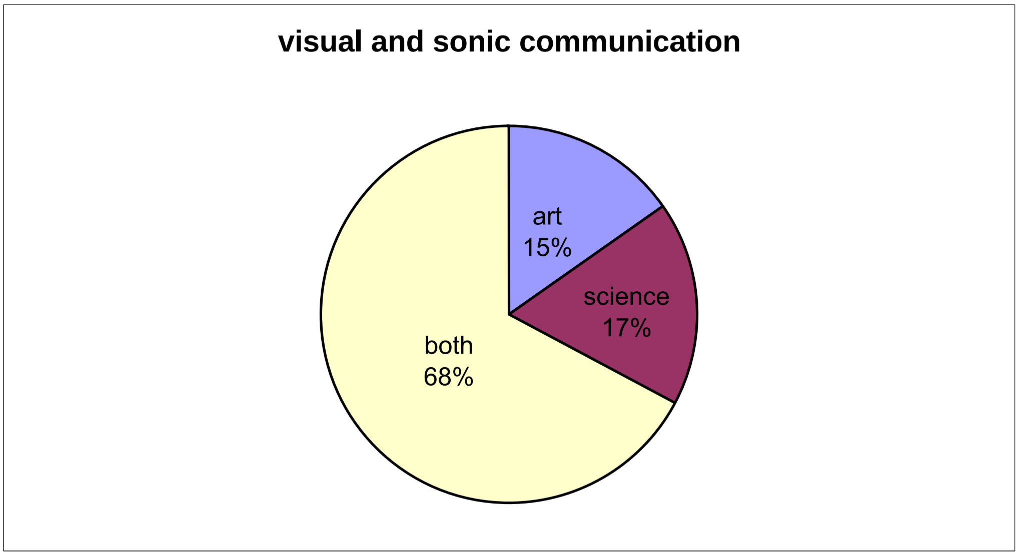
age	art	science	both	tatal
14	0	2	6	8

15	6	2	18	26
16	2	5	11	18
total	8	9	35	52

15 visual and sonic communication

age	strongly agree	partially agree	neither

age	art	science	both
14	0.00	25.00	75.00
15	23.08	7.69	69.23
16	11.11	27.78	61.11
total	15.38	17.31	67.31

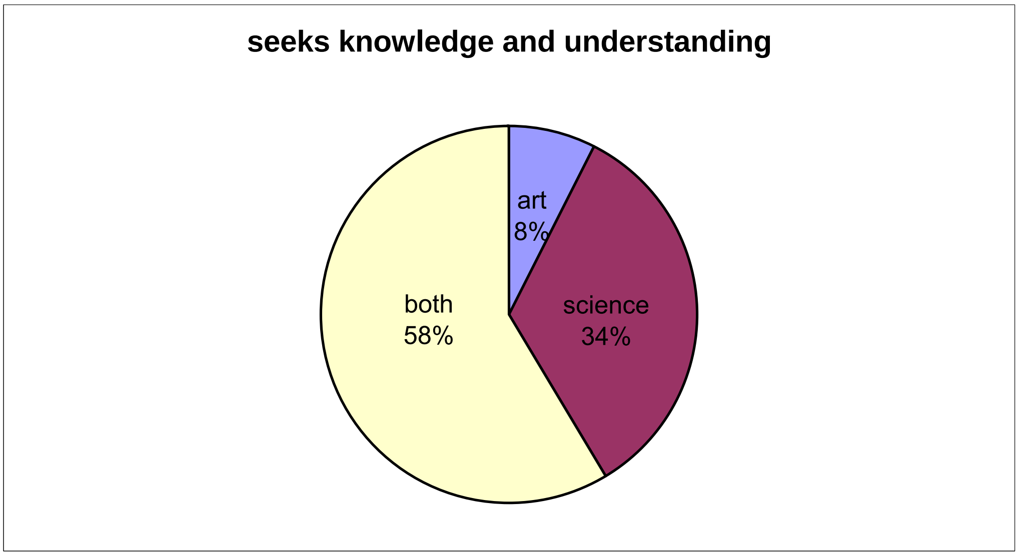


age	art	science	both	tatal
14	1	3	4	8

15	2	8	17	27
16	1	7	10	18
total	4	18	31	53

15-h Seeks knowledge and understanding

age	strongly agree	partially agree	neither
age	art	science	both
14	12.50	37.50	50.00
15	7.41	29.63	62.96
16	5.56	38.89	55.56
total	7.55	33.96	58.49



age	art	science	both	tatal
14	0	3	6	9

15	2	6	21	29
16	0	5	11	16
total	2	14	38	54

15-i Which area is based on reason

age	strongly agree	partially agree	neither
age	art	science	both
14	0.00	33.33	66.67
15	6.90	20.69	72.41
16	0.00	31.25	68.75
total	3.70	25.93	70.37