

# SCIENCE INFORMED DESIGN: INVOLVING THE PHYSICAL AND NATURAL SCIENCES

**John R McCARDLE**

Loughborough Design School, Loughborough University UK

## **ABSTRACT**

Eminent designers and engineers have historically been cited as inspirational polymaths with the ability to utilize a wide range of information to form a rational idea and create a concept. If educators are ever to encourage students of Design to emulate such skills then nurturing the growth of philomathic attitudes is essential. Part of that process is developing the ability to draw together observations from a far broader range of disciplines than those currently and commonly drawn upon in most design curricula, and integrating these into common practice.

Biomimetics offers many opportunities in design to broaden scientific inquiry. Such approaches currently lack formality as a design methodology and are consequently relatively scarce in application, but successful outcomes tend to capture student imagination. As such, biomimetics can provide an inspirational and highly educational direction for students to take and therefore has the scope to be a powerful learning mechanism.

This paper illustrates directions taken by design students of Product Design and Technology (BSc) and Industrial Design and Technology (BA). The interdisciplinary methods of studying, replicating and harnessing natural phenomena for design education and design practice demonstrates the potential as an avenue for learning that students considered inaccessible or even irrelevant. Above all it adds to the debate of designer skill sets and the need to bridge the current gulf between design practice and science.

*Keywords: Design, science, biomimetic, education.*

## 1 INTRODUCTION

The concept of multi-disciplinary design and inter-disciplinary working has been a well-established part of industrial design curricula at universities since the late 1960s. Since then the design of tangible products has seen a renaissance in methodologies driven by competitive business, market driven economies and the discerning user. More recently the inception of 'Design-Thinking' has supported creative methods in permeating business strategies, and knowledge of 'User-Centred' and 'User-Experience' approaches is now highly sought after. Business awareness and entrepreneurship are staples of many graduates around the world, but for design graduates especially, for whom the creative process is a vocation, an enterprising ethic is essential for surviving in such a competitive sector.

In terms of an educational philosophy the current understanding and prediction of future trends in design practice is demonstrated well by Paul Rodgers in his description of the 'polymath interpolator'[1], a term originally coined by Richard Seymour. Partly driven by the Cox review of 2005 [2], Rodgers expands on the notion of multi-disciplinary centres and the potential in education for the development of skill sets that cross traditional boundaries. However, the framework for this has its emphasis on marketing, commerce and economics. While no doubt such acumen is a valuable generic asset in the modern world, it further exposes an omission within design education, and that of polymath tendencies, that include a fundamental knowledge and sense of enquiry in science.

Many aspects of engineering and technical product design are deeply rooted in the physical sciences while designing as an activity is neither accepted as a science in itself nor defined by the application of science [3]. Nevertheless, the outcomes of design practice in these fields are a manifestly tangible link with both the physical sciences and, in most cases, with the arts.

While contemporary thinking on design practice and education may have a political and economic drive, questions still persist as to how science based observation and practices have become so disjointed from design practice? Should the curriculum be changed to address it? And if so, in what

way can we expand on the already broad church of Design to provide a mechanism that spans across more aspects of the sciences?

## 2 DESIGNERS ENGAGING IN SCIENCE

Historically, the comparisons and links between design, designing and science as an empirical practice have been well discussed. In his seminal work of 1969, Herbert Simon made the profound distinction with the statement, “the natural sciences are concerned with how things are whereas design, on the other hand, is concerned with how things ought to be’ [4]. The complete paradox between design and science as a fundamental methodology has prompted attempts to rethink the nature of designing and the proposition of it as a human driven technological activity perpetuated by non-scientific knowledge [5].

Although this can be supported through citing a number of instances of innovation and invention that have surfaced without scientific underpinnings [6], it is without doubt that the perfecting of resulting designs has been through the understanding and prediction of behaviours rather than heuristic approaches. That is to say, by undertaking empirical studies to provide explanations, rather than relying on time consuming and uneconomical trial and error or even tacit knowledge.

While designing may not be thought of as a scientific activity there should be little doubt that scientific enquiry is a valid, if not crucial part of design methodology. Science informed design plays a vital part in the development and improvement of concepts. Nevertheless, while this is incontrovertible with the physical and human sciences it is less well defined for the natural sciences.

## 3 DESIGN, SCIENCE AND BIOMIMETICS

Within research texts evidence for direct collaboration between designers and scientist, especially those in the natural sciences, is relatively scarce. But of course there have been a number of notable design outcomes that although not necessarily the result of collaboration, claim inspiration from the natural world, including de Mestral’s famous, if not clichéd, hook and loop fastener.

The term *biomimetics* seems to have been originally derived by Otto Schmitt in the 1950s as branch of biophysics and its link it with applications of technology. Although largely disregarded until the 1990s, save a few notable applications, biomimetic principles are being increasingly recognised as a route to inspiration for designers in the search for new materials, mechanisms and processes. It is proving to be a means to reach new heights of innovation and efficiency. These include the specifics of reducing viscous drag, engineering tactility, structural mechanics and self-healing properties, naturally sustainable systems and methods in AI.

There is a deepening interest in the field of biomimetic practices within Europe and the USA. Research groups are working towards developing design methodologies, biological ontologies and creative methods like BioTRIZ, a biomimetic version of the very successful TRIZ approach [7]. With strong evidence to suggest that designers and engineers can learn from and employ ‘nature’s solutions’ to solve many diverse problems, there is an increasing number of regional and international networks of academics and practitioners that are being set up to support interdisciplinary collaboration. These include Biomimicry UK [8], Biomimicry 3.8 in the USA [9] and the AskNature organisation [10].

## 4 BIOMIMETICS IN DESIGN EDUCATION PRACTICE

There follows two case studies each of which explored the possibilities for undergraduates to engage in research methodology that is both scientific, empirical and designerly. The first was aimed at innovative materials and manufacture ultimately for use in bicycle helmets, and involved the analysis and replication of the impact properties of trabecular bone, a natural structure found in specific areas of skeletons. The second example assessed the surface texture application capabilities of additive manufacturing technologies with the intent of providing experimentation in viscous drag reduction. Its purpose was to compare the drag factors of textures inspired by aquatic animals ultimately to explore potential surface coatings for boat hulls.

The context of this work centred on final year undergraduate project work, the object of which included the pursuit of innovation in product design. The work itself forms the dissertation aspect of the final year curriculum where students are expected to engage in a valid area of design centred research that elicits primary information. In the case of these projects, knowledge gained from

experimental work was used to inform design decisions either in major projects or generic manufacturing problems.

#### 4.1 Education in Mechanics, Materials & Manufacture

Natural trabecular bone consists of a complex network of interlinking rod-like and/or plate-like architecture, and is found in varying proportions depending on the anatomical site of the skeleton. There is significant evidence to support the theory that complex trabecular architecture found within natural bone has impact and shock absorbing properties. The location of trabecular bone occurs in areas of natural skeletons subject to high impact and stresses, where the arrangement of the individual trabecular is oriented according to mechanical stimulus. This study investigated whether natural trabecular architecture can be effectively replicated in samples of laser sintered Nylon as part of an engineered manufactured approach to high impact products such as bicycle helmets.

Trabecular bone was idealised into a hexagonal cell theorised to replicate the natural structure to suit a chosen method of manufacture. The structure was modelled in Solidworks 2013 (Figure 1.A & B), and combined together into flat samples to form a network of interlinking cells sandwiched by 1mm thick plates. Two sets of samples were produced with trabecular thicknesses of 1.0 and 1.5mm, and x, y, z dimensions of 54.5 x 59 x 9mm respectively (Figure2). As a comparison, two other samples were produced excluding the trabecular architecture. These solid samples had identical x and y dimensions, and measured 2mm and 9mm in the z-axis.



Figure 1. A: 1mm trabecular model B: 1.5mm trabecular model

All samples were subject to impact testing using a falling dart drop impact test (Figure 3). The specific property investigated was the material toughness, or energy absorbed before fracture. As expected the solid samples produced the highest value of energy resistance, but compromised weight and overall cost. The 1.5mm trabecular architecture did not demonstrate significant effective energy absorption or gradual deceleration but the 1.0mm architecture represented a failure similar to that of natural trabecular bone. The individual trabecular at this scale buckles prior to ultimate failure, thereby increasing the energy absorption of the material, and increasing the time to ultimate fracture.



Figure 2. Idealised trabecular specimens

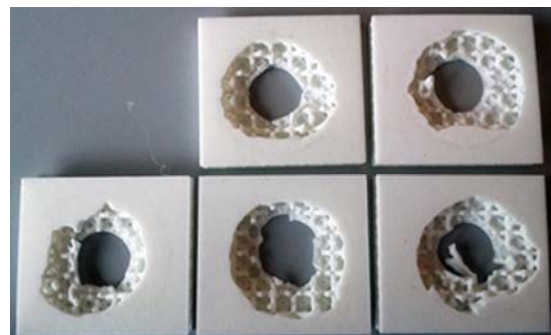


Figure 3. Following impact testing

The study determined that the synthetically replicated structures demonstrate significant energy and impact absorbing capabilities (Figure 4). The information gained from the research was useful in considering the design of impact and shock absorbing components of the product, with an emphasis on efficient use of material mass which could be engineered through the manufacturing process. The final design of the helmet is currently under development and consequently IPR restrictions.

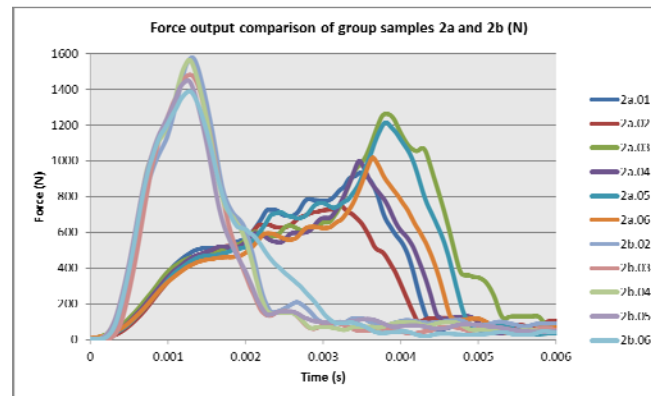


Figure 4. Overall energy absorption results

#### 4.2 Education in Fluid Dynamics & Rapid Prototyping

As in the previous example, the increasing cost effectiveness of additive manufacturing (or rapid prototyping) processes provides opportunities to manufacture products without the traditional constraints of scale. The possibility of creating and experimenting with micro-textures, inspired by nature, becomes more realistic. Such varying textures are found on animal skin and in some cases the nature of the texture is theorised to reduce viscous drag, for example the skin structure of a shark. Within the animal kingdom, aquatic animals are considered to be some of the most widely adapted creatures within their environment. What seems an effortless movement at speed underwater is not only a consequence of the highly evolved muscle groups providing propulsion, but also the streamline form and low surface friction.

For this project the objective was to apply different textures onto the surface of spheres produced via an AM Objet Connex machine scaled at 3 times the original, natural size. Skin details from Shark, Trout and Starfish were idealised (Figure 5) and Creo was used to create the spheres. The experiment itself was simple and well-tried and consisted of dropping the spheres through a fluid of known viscosity and recording the time to calculate the rate of travel (Figure 6). While this experiment may be considered somewhat crude in the age of CFD, the costs and time associated with the necessity of supercomputing power to handle the complex surface structures precluded this possibility.

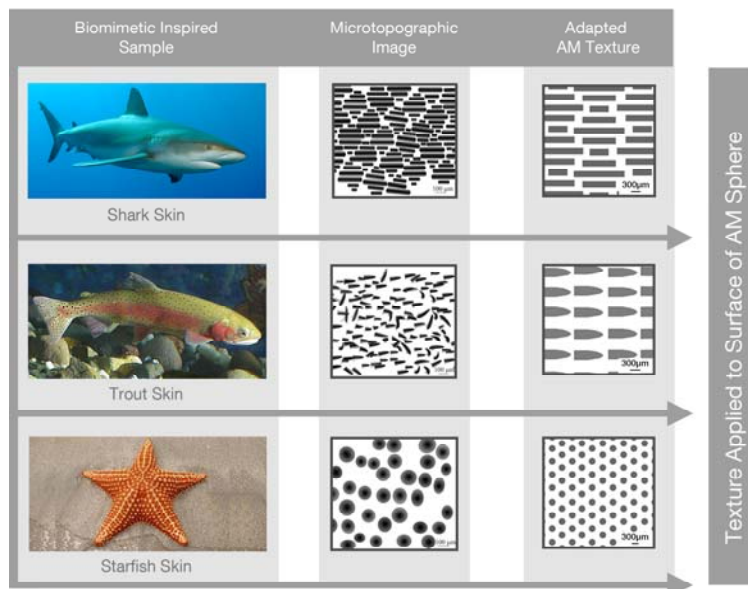


Figure 2. Summary of aquatic surface textures

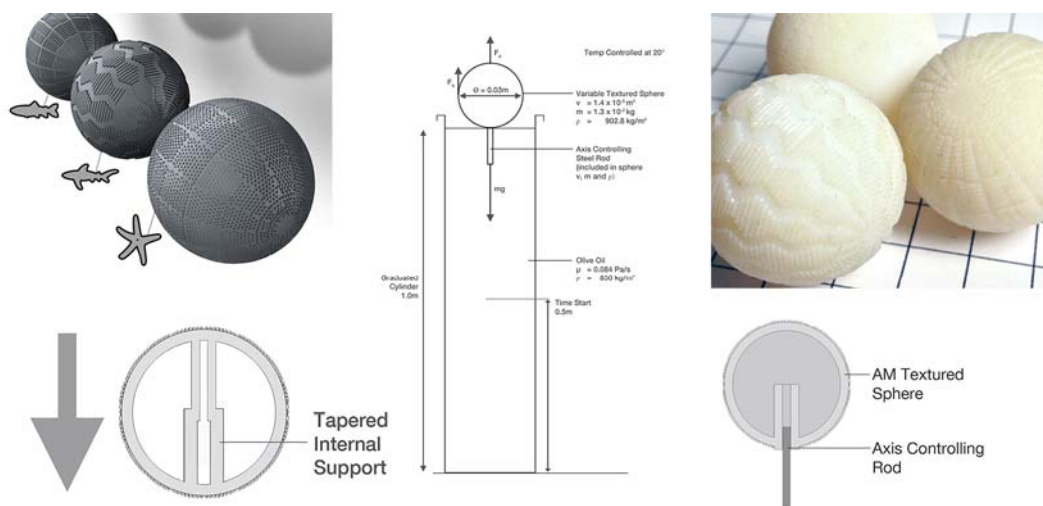


Figure 3. CAD modelling, experimental detail, AM specimens

The results found that in laminar flow, perhaps surprisingly, the starfish skin had the least drag, following the trout and finally, the shark skin. It was suggested that due to the nature of trout and shark, as the Reynolds Number increases, so does the effectiveness of their textures to reduce drag. It was also identified that as the surface area increases, it seemed to reduce the skin friction drag, implying that the surface area improves flow adhesion, which in turn could reduce the amount of flow separation and pressure reducing wake pockets. When the spheres were compared to a theoretical smooth reference sphere, the textures showed an increase of viscous drag of up to 30%. While some of the results were far from definitive and in a number of areas counterintuitive, the data and the hypothesis provided significant input to further discussions for the development of products between manufacturing engineers and fluid dynamists.

The applications for manufacturing a viscous drag reducing texture could range from the hull of a boat to aerofoils to sportswear and even anti-bacterial surfaces. Practical applications already exist including mimicking the ribbed texture of shark skin for advanced swimwear. Indeed, for this project a treatment for the hull of boats that is based on the barnacle repelling texture of starfish already exists, although perhaps unknowingly with the possibility of additional efficiencies.

## 5 CONCLUSIONS

While there is a constant reciprocating transfer of knowledge between educational institutions and industry, the future of creative Industrial, Product and Engineering Design begins with the education of students. There is currently a strong urge within the HE sector to provide students with grounding in business and entrepreneurship while the underpinnings of scientifically sound problem solving are often neglected.

Encouraging and supporting the development of a broad set of research skills, including those of the natural sciences, offers exciting opportunities to drive surprisingly innovative design solutions. The notion of biomimicry, although currently without the degree of formality of other creative design methodologies also offers the opportunity for problem based learning approaches and to explore new technologies.

Regardless of a scientific background biomimetics can be used to support design students in developing key skills of interdisciplinary working, empirical methods and subject specific knowledge that is both relevant and empowering.

When considering prototype manufacture, the increasing resolution and cost effectiveness of rapid prototyping technologies provides opportunities for the development of products derived from organic structures negated by typical manufacturing constraints.

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