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Opinion Piece

Science versus design; comparable, contrastive or conducive?☆

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ABSTRACT

Science and design are two completely separated areas of expertise with their own specialists. Science analyses the existing world to create new knowledge, design uses existing knowledge to create a new world. This tunnel-vision mentality and narrow-minded approach is dangerous for problem solving, where a broad view on potential solutions is required to realise a high-quality answer on the defined problem.

We state that design benefits from scientific methods, resulting in a more effective design process and in better products, while science benefits from a design approach, resulting in more efficient and effective results. Our philosophy is illustrated using examples from the field of biomedical engineering.

Both methods can benefit tremendously from each other. By applying scientific methods, superior choices will be made in the design process. With design, more accurate, effective and efficient science will be performed.

1. Introduction

As many at his time, Leonardo da Vinci was a scientist, designer and artist: after a scientific study of bird flight he was able to design an airplane. Nowadays, specialisation generally brings us to consider science and design as fully separated and fundamentally different domains (Fig. 1). Design aims at realising a new world from existing knowledge, while science aims at realising new knowledge from the existing world. Design starts with defining the goal and function (analysis) to end with a structure (synthesis); science starts with a structure (synthesis), defines its function and finally its goal (analysis).

Also in practice, science and design are considered to be completely different (Divall, 1991). Grant (1979) stated this clearly: 'the act of designing itself is not and will not ever be a scientific activity'. And Fallman (2007) stated: 'The difference between academic science and commercial design needs to be recognised and made explicit. It is simply too much to do both good design, with a happy client, and good science, with happy peers'.

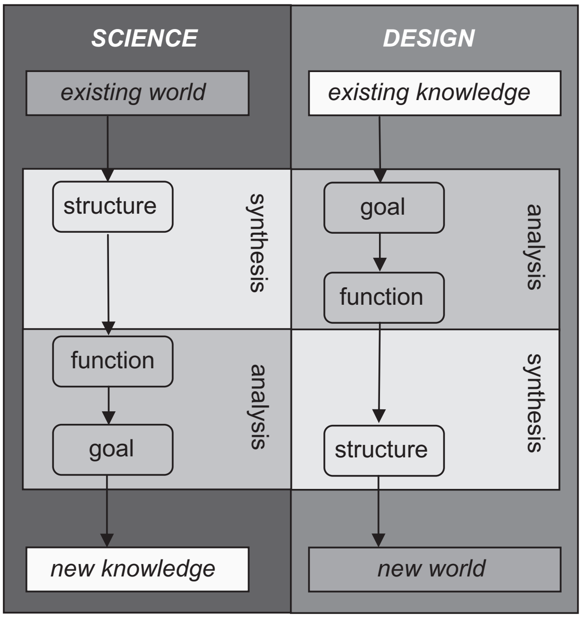

Fig. 1 – Differences between science and design.

Some attempts have been made to bridge the two. Kesselring (1942,1954) already discussed the link between design and science. Gregory (1966) introduced the term 'design science', meaning that design is, like science, organised in a systematic way (Cross, 2007). Glanville (1999) even envisioned science is a restricted form of design: when scientific questions are answered, they create many more new scientific questions. Such a circular process is also present in the design process. A third link is that design as a method may be the subject of scientific investigation (Grant, 1979; Restrepo and Christiaans, 2004; Cross, 2001). This made Fallman (2007) to introduce the concept of 'design-oriented research', being the study of the designed product in use, or of the process of bringing the product into being.

Indeed, all of these studies presented analogies between science and design, mainly focused on their characteristics, rather than on the methodology or content of the process: the only similarities found are that both are structured, iterative and systematic. Each process has a unique and different methodology and goal: science studies the world to create new knowledge, design uses knowledge to create a new world. Because of this distinct difference, both the methods are applied fully independently, each by its own specialists: scientists and designers.

The goal of this article is to show that this strict separation between science and design is counterproductive. Design needs science and science needs design. When the two methods are used in addition to each other, both methods benefit: both become much more efficient and effective.

2. Science

In this article, science is schematically considered as the generation of a hypotheses or models that are confirmed or falsified by experimental research, producing new knowledge in repeatable and unambiguous fashion. Science is coherent: the outcome, new knowledge, fits existing knowledge and is consistent with it.

Knowledge is expressed in terms of relationships among events or variables. Scientific experiments permit to determine these relationships by monitoring the change of relevant variables as one of them is varied (Glanville, 1999).

3. Design

In the 20th century design evolved from an arts-and-crafts movement to a specialism taught at university level worldwide. Influencing pioneers originated from Germany (Kesselring, 1942,1954; Tschnochner, 1954) and the UK (Bernhard, 2004; Forty, 1986). The 1962 ‘Conference on Design Methods’ is generally regarded as the event where the concept of *design methodology* was introduced (Cross, 2007; Jones and Thornley, 1963) according to which design is considered as a process occurring through several successive phases. Since then many design methodologies have been developed (Grant, 1979; Zeiler, 2007; Stevens, 1993; Horvath et al., 2009). These different methods are in essence comparable and can be divided as follows (Zeiler, 2007):

1. the given problem is analysed extensively, since problems are often described incompletely (Restrepo and Christiaans, 2004); the fundamental problem is defined; the goal and required functions of the solution are defined and a list of requirements is made;
2. in the synthesis phase, numerous alternative solutions for the formulated fundamental problem are generated to increase the chance of generating the optimal solution;
3. the best solution for the problem is selected by evaluating the solutions on meeting the requirements;
4. tests are performed to make a proof-of-principle;
5. the product manufacturing process is developed;
6. the selected solution is shaped into a product and introduced in society.

Each phase is again divided into sub-phases to concentrate on a small part of the entire work at a time.

The design process is not straightforward, rather it is iterative and has feedbacks (Zeiler, 2007). So the design process is very clearly structured; all phases must be performed in a strict way and order. Even for the creative synthesis phase, where solutions for the fundamental problem are realised, several structured methods have been developed, like TRIZ (Altshuller, 1988).

The various design methodologies differ only in details:

- a specific focus can be included, as on recycling (McDonough and Braungart, 2002) or assembling;
- ideas may be generated from examples from nature (Lavine et al., 2005);
- specific routines can be applied to some sub-phases (Stevens, 1993; Matthews et al., 2002).

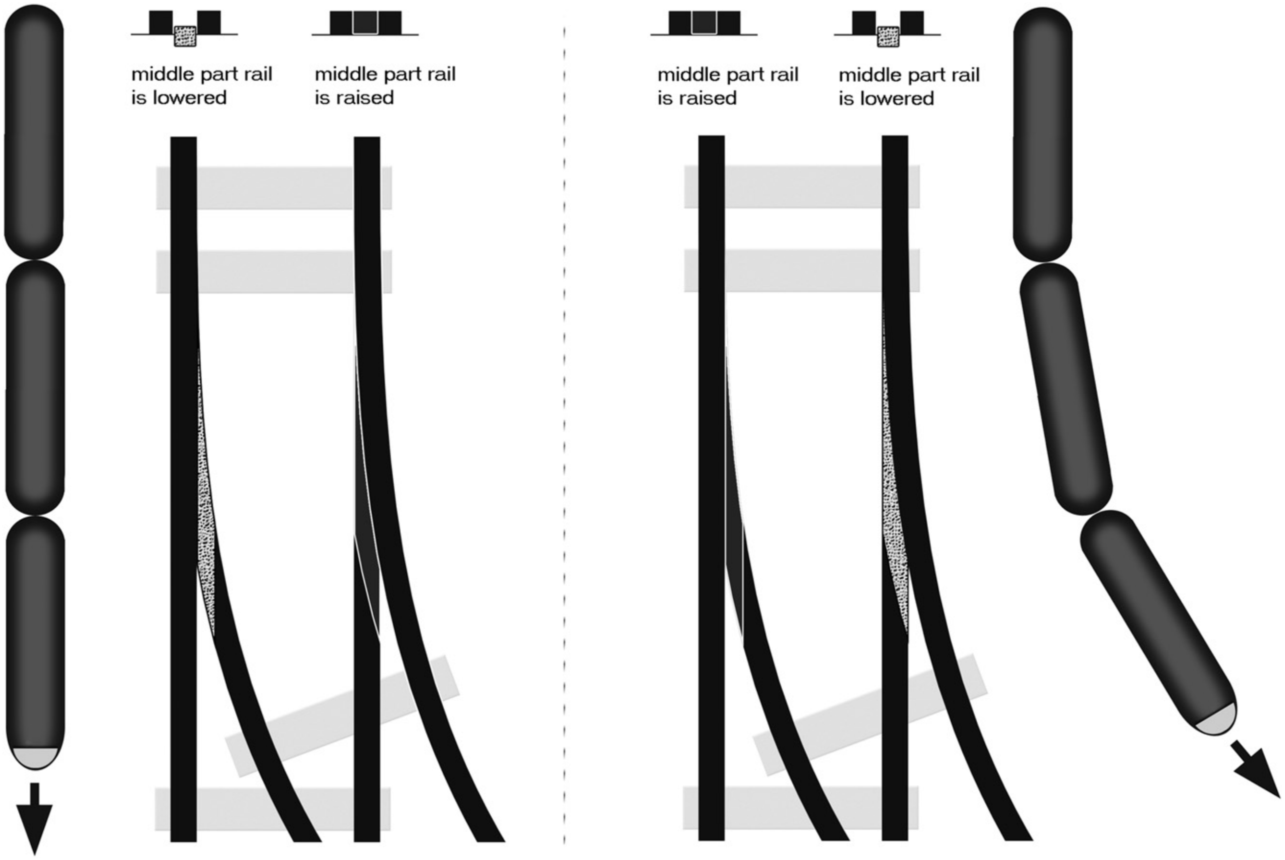

Fig. 2 – New design of a switch with vertical moving parts.

For this article the essence of design methodology may be summarised as follows:

- Extensive analysis of the problem to identify the most fundamental problem(s).
- Definition of a list of requirements.
- Generation of numerous alternative solutions.
- Selection of the best solution meeting the set requirements.

3.1. *Case study 1*

A typical example of the importance of a proper problem analysis is apparent in the winter season, when snow hinders the railway system. Ice piles from below trains, falling in railway switches are considered to be the main problem. As a solution gas or electric heating systems are applied on switches, but they are not able to cope with these large piles of ice. The limited capacity of the heating system is considered to be the main problem. However, increasing the capacity often appears to be not sufficient. Teams have to drive to the relevant switch to remove the ice, a very poor alternative, because it requires much time. Ice formation under the trains is also considered the main problem, but this is also difficult to solve the problem. So actually there is no practical solution for this problem. A more extensive problem analysis is able to unravel the real problem: the functioning of the switches is very vulnerable to disturbances. Every small object, falling between the moving and fixed rail is able to block the switch. After defining the problem in this way the solution is very easy and robust: a new switch design that consists of *vertical* moving parts is not vulnerable at all to falling objects, they just will be driven out of the switch (Fig. 2).

4. Design needs science

The design process is *indirectly* associated with science: In the design process numerous alternative solutions are generated, based on existing knowledge acquired through scientific processes. Science improves on the design process also *directly*:

- When requirements are not known (e.g. what is the maximum load a new hip prosthesis has to withstand?) scientific research helps quantify them.
- Judging the various concepts that have been created on basis of the requirements often requires building prototypes and testing them. A scientific approach for prototype testing will increase the quality of the assessment. The same holds true for the final prototype testing.
- In case of mal-functioning or non-functioning of a product, science is required to find the underlying physical mechanisms. With this knowledge, a better alternative solution can be designed. Typical example is how the Comet airplane crashes initiated fundamental research on metal fatigue. This process of knowledge initiation is known as ‘Design science research’ (March and Smith, 1995; Vaishnavi and Kuechler, 2007) or ‘Research-oriented design’ (Fallman, 2007).

The application of science to design is often termed ‘applied research’. So without science inferior designs will be produced.

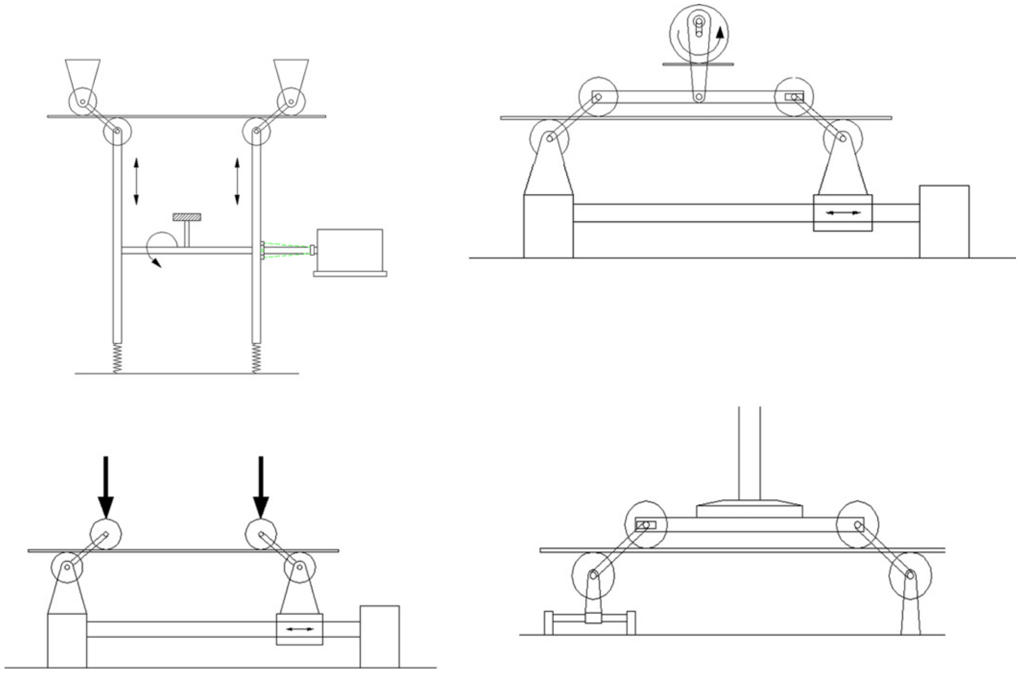

Fig. 3 – Four different concepts for a fatigue bending test set-up.

5. Science needs design

There are four major reasons why experimental science needs design:

- Scientific projects in general and on biomedical materials research in particular must rely on the use of specific measuring systems, equipment or processes to pursue its experiments. The design of such a device can 'colour' the outcome of the very experiments they are created to assist and can and has lead to results which are often meaningless and even have the wrong answer to an hypothesis. The design process is able to create the best possible measuring device or process. In this way design is critical to the success of any scientific project.
- With an experiment the influence of a variable on the behaviour of a biomedical material is investigated. It is often planned based on the first intuitive idea of a strategy for such an experiment. However, the principles of the design process are very useful for devising a more effective experimental strategy:
  It forces a more extensive reasoning on the real fundamental goal of the experiment. Then a list of requirements is defined. Subsequently, various strategies are created that differ, for instance, for the order in which variables are varied. Finally the strategy that meets the requirements best is selected. This strategy is most likely to be better than the first, intuitively created one, and thus will increase the quality of the experiment in terms of accuracy, duration and the number of required samples.
- Test setups, in which one parameter is varied and its influence on the environment is assessed, are also often realised based on the first intuitive concept development. The design approach that creates more setups and selects the best one will most likely maximise ease and speed of handling, measuring accuracy, and reproducibility.

So without design we produce science of inferior quality.

Ultimately, science needs design, because design justifies science. Design uses scientific results to create a better world for society. If scientific results are not applied in design, society might get convinced that science has no practical right of existence. So without design, ultimately there would be no science.

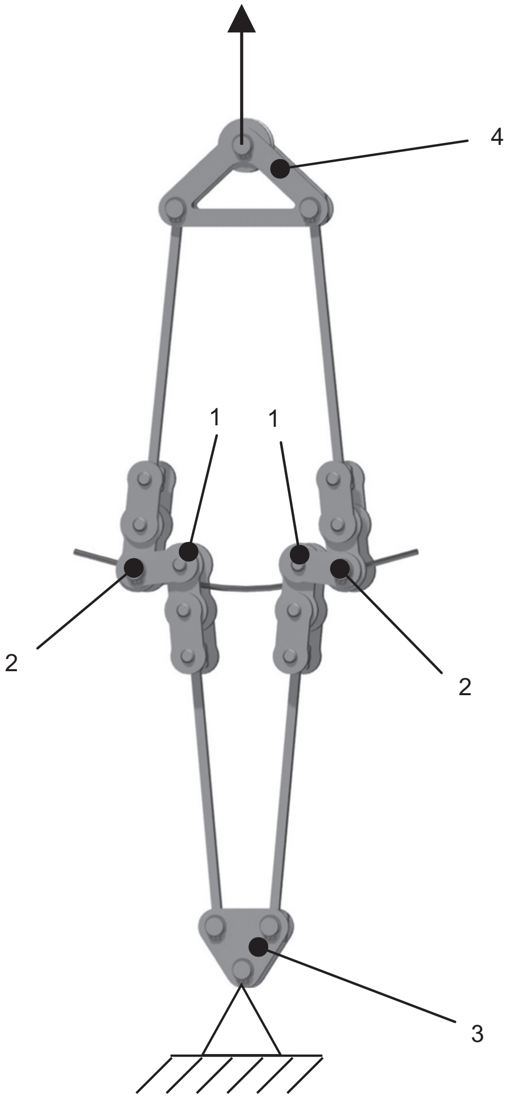

Fig. 4 – Bending test set-up. Four supports facilitated the bending of a NiTi rod. Two outer supports (2) translate vertically, initiated by a vertical translation of the upper triangle (4) which was pulled by a wire connected to a camshaft. The inner two supports (1) were restrained vertically by the lower triangle (3) that was fixed to a frame.

5.1. *Case study 2*

Memory metal (NiTi) is used more and more as implant material, both for its memory properties and for its pseudoelasticity. For scoliosis correction both properties are very useful (Veldhuizen et al., 1997). However, the fatigue properties of NiTi are less favourable; moreover, due to stress- and temperature-induced phase transformations the NiTi fatigue behaviour is complex and unpredictable. In general fatigue tests are force-induced, but the methodical design process forced the researchers to think of the main goal of the set-up, which appeared to be a strain-induced loading, since the scoliosis correction rod will follow the bending behaviour of the spine during daily activities. The methodical design process was applied to develop a four-point bending set-up and thus instead of one design, several concepts were created (Fig. 3). This forced the researchers to formulate the different functions of the set-up.

To select the best one it was necessary to formulate a list of requirements. This forced the researchers to consider the conditions under which the set-up had to function. Selecting the best concept using this list of requirements clearly showed that even the best design still had a few shortcomings. Often, the rejected alternatives give solutions how to overcome these shortcomings. So merging several concepts into one increased the quality of the final concept. This is another benefit from creating several concepts instead of being satisfied with one. The final result of the set-up, depicted in Fig. 4, appeared to be very efficient and effective in practice.

6. Discussion

The requirements of regulations that all decisions and considerations made during the design process are traceable make a methodological approach of the design process very beneficial, because it forces to take well-pondered decisions and streamlines the documentation process by its division into phases and sub-phases. This is particular important for new biomaterials applications and new medical devices.

The design process is characterised by its extensive analysis of the problem, definition of requirements, generation of solutions, and selection of the best solution prior to actual manufacturing of the product; all for the sake of solving a specific problem. When we realise that problems occur everywhere and at any time, the design principles should be used everywhere. Surprisingly, they are not. Even technical disciplines have a paucity of design-led training. Only in mechanical engineering, chemical engineering and industrial design are they instructed on a routine basis (Cross, 2007). Just recently it is introduced in chemistry (Horvath et al., 2009; Wesselingh et al., 2007; Cussler and Moggeridge, 2001) and informatics (Fallman, 2007), which has benefited from user (or human) centered design philosophy (ISO Tech. Rep. Ser. No. 13407, 1999). Since technical disciplines hardly teach the design principles, it is not surprising that they are not applied in science teaching.

6.1. *Case study 3*

Also in Biomedical Engineering a methodical design process is rarely used. When considering the development of hip prostheses (Catapano and Verkerke, 2012), it is remarkable that the very first successful design, developed by Charnley, is hardly improved. Out of the box thinking is absent in many biomedical developments. And improving hip prostheses is still necessary, since the lifetime is limited and the increasing lifetime of man requires long-lasting solutions. Wear is one of the important reasons of failure. Charnly discovered this in a very early phase, because in his first attempt he used PTFE as material for the acetabulum cup with dramatic consequences in terms of extensive wear and aggressive wear particles. Obviously, mulitidisciplinary design teams were not common these days. Only after this failure he consulted engineers who advised him to use UHMW-PE that appeared to be very successful. However, disastrous material choices are still made, considering the metal-on-metal hip prosthesis (Smith et al., 2012). To decrease wear, one solution is optimising the materials combination, but other, less obvious solutions are hardly considered (which again proves the lack of a design approach): solutions with ball bearings, elastic hinges, cardan joint, lubrication, collars that shield the prosthesis from the body and thus prevent that wear particles cause inflammation.

Another reason for failure is the transfer of load from the hip prosthesis to the bone. From a mechanical point of view the current design, composed of a stem in the marrow cavity is a weak solution, since loading of the femur is far from natural, resulting in major bone resorption (Tomaszewski et al., 2010, 2012a). New developments focus on a single problem only and thus offer a partial solution, which of course is prone to failure. The introduction of a collar should improve axial load transfer, but not bending load transfer. The use of materials with matching Young's modulus should improve bending load transfer but not axial load transfer. So due to incremental thinking a non-optimal solution is created. A proper problem analysis should have made clear that there are two problems to solve. Only then a good solution can be found for natural load transfer, natural loading of the femur and thus in preventing bone resorption. Test of a recent development in fixation systems to the femur that focused on both problems instead of one confirms this statement (Tomaszewski et al., 2012b).

7. Call for a change

Specialisation brings along the risk of developing a tunnel-vision mentality and narrow-minded approaches to problem solving. In engineering education, science and design are fully separated and thus a tunnel-vision is created. We strongly believe that integrating both is necessary as part of a new way of educating engineering students. Introducing design methods in scientific disciplines may help reversing this trend. Their contrastiveness should be explained and benefits should be made clear. Scientists should be trained in a methodical design process to solve problems with a broader-minded approach. It should be made clear that a badly designed test set-up creates wrong results, leading to meaningless or even wrong conclusions.

Designers should be trained in scientific methods and especially when and how to apply them in the design process.

This will create better researchers and designers, the former capable of using design methods for performing valuable and meaningfull scientific research, the latter of integrating scientific methods, resulting into better products and solutions for the needs of society. More than this, if both are capable of understanding and interacting with one another, this will eventually make science and design conducive and even indispensable to each other.

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