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First Make Something – principled, creative design as a tool for multi-disciplinary research in clinical engineering

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First Make Something

Principled, creative design as a tool for multi-disciplinary research in clinical engineering.

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Abstract

Design provides a set of tools for exploring our world and these can give very different insights from the tools of the natural scientist or social scientist. The Art and Design Research Centre at Sheffield Hallam University is developing the use of creative practice at the centre of multi-disciplinary research and has demonstrated that this approach can bring significant results in areas of research which are more usually thought of thought of as science or engineering.

This paper describes a 3-year project which has provided completely new ideas for the design of artificial limbs based on close analogies with human anatomy. The project was intended to look at very long-term developments but has also resulted in ideas for today's products and has changed the thinking of both clinicians and manufacturers.

Investigative methods included iterative cycles of creative development and reflection; work with users including the production of video material to stimulate their thinking beyond the state of the art; and both qualitative and quantitative evaluation of design outcomes with scientific and clinical specialists.

1. Introduction

This paper describes a research project which uses creative design activities to explore an important human need, for effective prosthetic arms, in a field which is more usually the preserve of technologists and clinical researchers.

The development of a research culture in design has not been an easy journey for practitioner academics whose experience and aptitudes might lead them more naturally to pragmatic interventions in the world rather than detached observations of it. However, alongside research methods drawn from the natural and social sciences, there has been a growing interest in practice centred research, in which creative work is seen as an essential, central part of the research process, rather than its subject or end-product.

Bruce Archer (1995) has described a range of approaches to research in design, including research into design, research for design and research through design. He also makes a clear case for "action research" in design. However, the visible face of design research is clearly research into or for design. At the 1999 European Academy of Design Conference 48 papers were presented and all but 5 were clearly "about" design. There were a small number of "Practice Based Presentations" and these were more clearly of investigations being carried out "through" design.

The approach adopted by several practitioner/researchers in the Art and Design Research Centre (ADRC) at Sheffield Hallam University has emphasised the possibility that design, like the sciences, can be a tool for exploring the world and this paper, while being in part "about" design research, sets out to present the outcomes of such an investigation.

The ADRC approach has been to act as a catalyst for multi-disciplinary work by developing practical creative responses to a stated situation. In some respects this process could be likened to the forming of a hypothesis in other areas of research and one collaborator from a "scientific" discipline has suggested that scientists are frequently engaged in creative synthesis but fail to value it sufficiently, the emphasis being on analysis and proof. Projects in which this approach has been used include.

- The provision of stimulus for people with profound sensory deprivation (Roddis et al)
- Re-use of waste glass with minimum energy input. (Chamberlain et al)
- The provision of prosthetic arms with the potential to provide natural movement.

This last topic is the subject of this paper. It is notable that many of the published outputs from these projects have been through conferences and journals which are not concerned with design since the aim in each case has been to inform development in other disciplines.

2. The Project - Reproducing Natural Human Movement

The research project, which has been running for more than three years, started when the researchers observed that existing prosthetic arms are not capable of natural movement, since they are based on a very simplistic mechanical analogy with human anatomy. They believed that this was very significant for the self-esteem of the people who need prostheses.

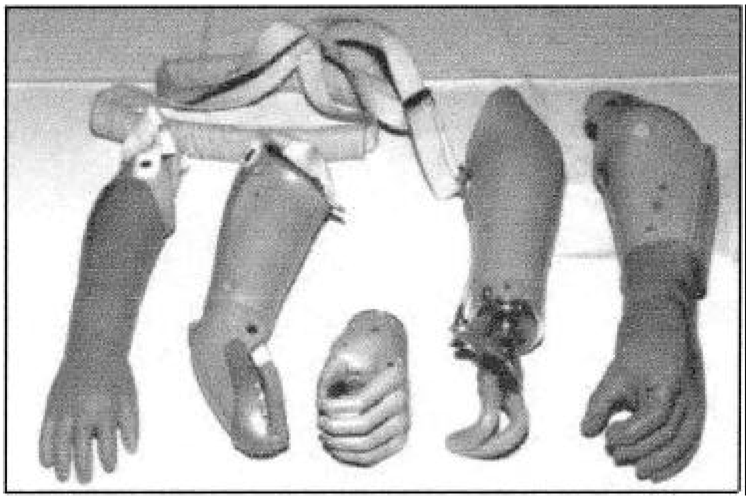

Fig. 1: Some existing prosthetic arms

The team set out to create a set of mechanical design principles for a naturally articulated prosthesis. The main vehicle for this is the production of a series of demonstration models leading to a complete analogous model of the hand and arm. In doing so they were aware that their designs would require actuation and control technology which do not exist at present, but they believed that, without such a mechanical "test rig", developments in these technologies would be inhibited

It was also felt that the pursuit of an analogy would bring functional benefits to users. It was not possible to predict these benefits but the team took the position that a design which was very close to the original anatomy would be better integrated with the user and potentially capable of matching at least some of the functions of the original arm. This philosophy is very different from the approach taken in the development of existing arm prostheses, which have been focused on functional tasks and a piecemeal approach based on interconnecting modules which can be configured for a variety of specialised needs.

3. Principles

In the absence of very specific design goals it was especially important to adopt a principled approach which would provide a framework for guiding the project and reviewing the work as it develops. The team also wished to explore and demonstrate a set of principles which might be helpful to other designers, especially those involved in multi-disciplinary work.

The most central idea was the observance of very close analogies with the "design" of the original limb rather than the more superficial use of functional analogy. This idea was clearly very specific to this project although the use of analogy with natural "designs" has many less direct applications as described by Papanek (1985) and Steadman (1979). In addition there were a number of more general principles drawn from the experience of team members:

- Recognition that designers must investigate situations at first hand, as well as using published information or the experience of professionals from other disciplines.
- A conscious use of design methods, tools and work plans which acknowledge the iterative nature of creative work.

- An approach which requires that all elements of a design should be advanced in parallel, especially avoiding the temptation to improve something which has just been done, before bringing other parts of the design up to the same level of completeness.
- A wide consultative "team" which includes users, prosthetists, rehabilitation specialists, manufacturers and designers with a cultural focus as well as clinicians and technologists.
- The use of models, visualisations and prototypes to stimulate collaboration and encourage consideration of new ideas by people who may have developed a fixed view of the subject.
- The use of both documentary and fictional material on video to encourage users and professionals to debate their expectations and needs in both functional and cultural terms.
- An approach which focuses from the start on the need to adopt effective manufacturing methods to ensure that an eventual product is affordable and easy to configure and deliver to users
- Acceptance that some of the technologies required are, as yet, undeveloped, and that the role of this project is partly to stimulate their development and to provide an effective mechanical test-bed for other researchers.

4. Creative Activity

In the history of anatomy, some of the first investigations were conducted by artists who wished to better understand the human body. This project revisits that tradition since it seemed to be very important that the creative work was based on an intimate understanding of the original anatomy. Rather than relying on published information, the principal designer, Graham Whiteley, invested a good deal of time in observing and drawing the anatomical details of the hand and arm, working from observation of models and skeletons as well as working with illustrations and photographs. This work has been described in an earlier publication (Rust & Whiteley, 1998).

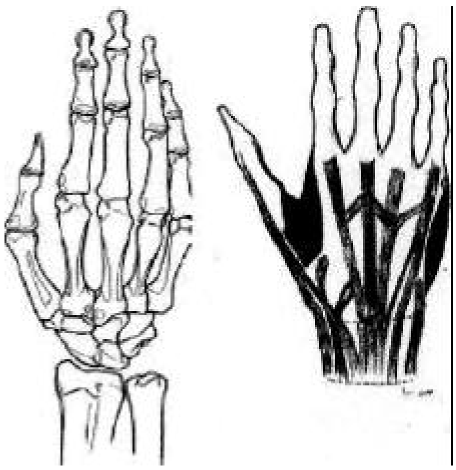

Fig. 2: 'Learning" the hand

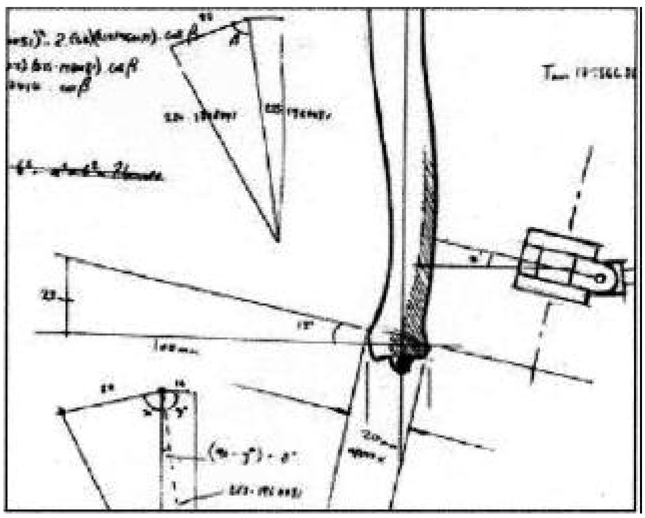

Fig. 3: Geometric analysis of the ulna

This process of learning and analysing the form of the joints was crucial since the central problem was to understand the motion of each joint and this is created by the interactions of several hard and soft elements. There has been research, for example by Besson (1997) and Karabinova (1997) in medical physics, measuring joint motion to create mathematical descriptions for anthropometric computer models. However this work is hampered by the fact that the skeleton is masked by soft tissue and it is extremely difficult to work accurately. It was felt that seeking to understand the joints was likely to be more productive than attempting to measure their action.

Drawing and making are also the central activity in the developmental work and it is important to stress that, while technical and scientific knowledge are important to designers in a project like this, it is the creative activities of drawing and making which allow ideas to crystallise. The main workspace for the project is a workshop/studio shared with other designers working on practice-based research projects and the very visible nature of practical design work makes it natural for the designers to provide continuous support and criticism to each other.

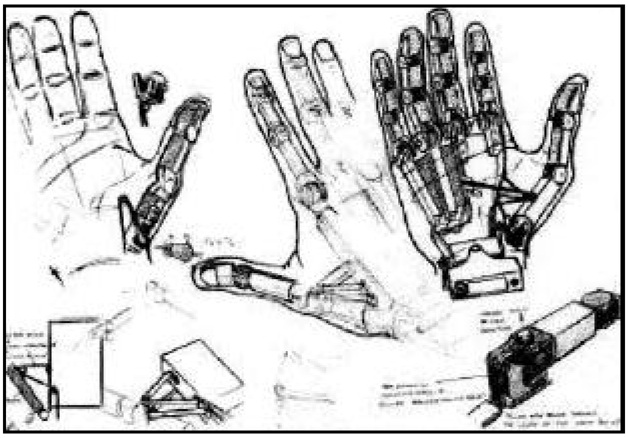

Fig. 4: Early concepts for hand joints

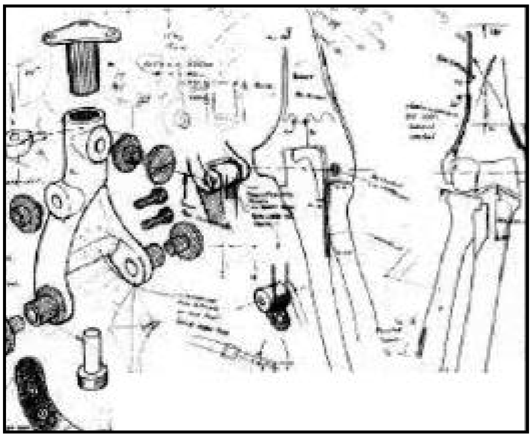

Fig. 5: Elbow development

The practical tools developed with the project. In the early stages, where complex but geometrically straightforward components were needed for the first attempt at knuckle components (Fig. 6), a simple CADCAM approach using 2^J/2D CAD software and a 3-axis router was used to give fast development and repetition of modular parts. Later on, when more subtle 3D forms were called for, (Fig. 7) most of the work was done by manual methods combined with conventional machine tools. Now that the basic geometry and design principles are established there is an increasing use of more sophisticated 3D CAD modelling to achieve accuracy, very complex soft forms and output to 3D prototyping

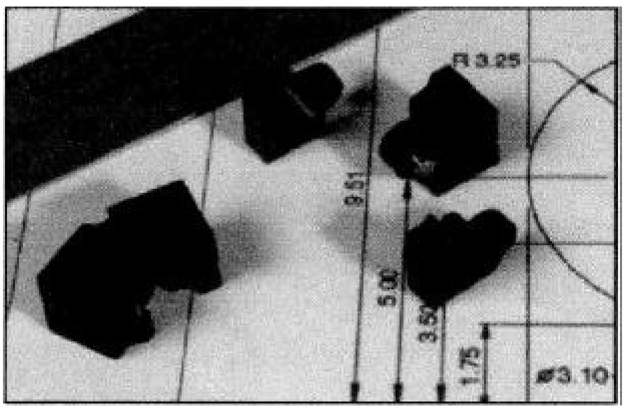

Fig. 6: First iteration of knuckle joints

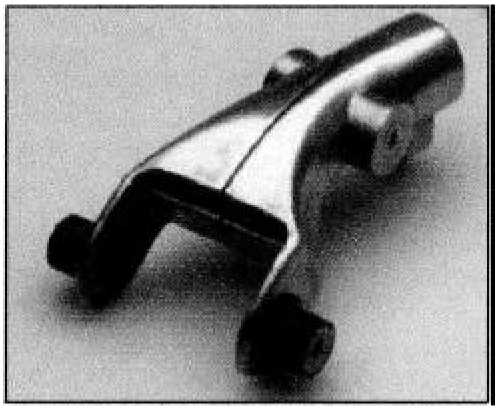

Fig. 7: Elbow component

It has been found, through using various prototyping resources at different locations, that relatively basic tools which are immediately to hand and under the direct control of the designer are generally preferably to more sophisticated resources which are some distance away or require the cooperation of people outside the research team. The effort and time delay involved in coordinating external resources tends to interrupt the flow of development work.

Cost is also a factor - where the marginal cost of re-iteration is high this acts as a brake on exploratory work. In theory the project team has access to a variety of sophisticated resources through university and industrial contacts, in practice it has been most effective to concentrate on getting results from the basic but well-understood machine tools and computer resources within the design school.

An approach such as this, which develops the resources and skills within the research team, is likely to have greater benefits for the research centre than one which seeks to use external resources. For example, rather than using an external contractor, the team constructed a basic vacuum casting machine to allow batch production of components for the project. This has had the spin-off value of allowing technicians to develop new skills and promoting the use of vacuum-casting as a creative tool by large numbers of students and researchers

5. Working with Users

From the start of the project it was seen to be vital to engage with the people who need prostheses. The principal designer became a member of a support group of prosthesis users, who meet monthly to discuss a wide range of issues. His position in the group was unusual in that he was not a user, nor was he one of the professionals who provided healthcare or services. His approach was to make it clear that he had no experience or knowledge of the field and he was there to learn about their experiences and their needs.

He made no claims for his design work other than to say that he was making a fresh start and had no connections with any previous work. This was very helpful, as the users were generally unhappy with the products that were available. He was younger than most of the users in the group, many of whom were experienced engineering workers who had lost limbs in industrial accidents. Generally they were pleased to "adopt" him into their group and interested in the opportunity to contribute to the project.

The members of the group could be regarded as "lead users" in the terms described by Von Hippel (1998). Only a small proportion of the total number of users in the region took part and some of them were willing to travel a considerable distance (up to 100km) to attend the monthly meetings. Several of the members were active in modifying their prostheses for specialist purposes and some took part in challenging activities such as flying light aircraft or riding high-performance motorcycles, making heavy demands on their prostheses. Some members had also formed friendships through the group meetings and met regularly to play golf or other social activities.

The regular meetings included formal and informal discussion of the whole range of problems and issues affecting the lives of prosthesis users, this has enabled the designer, during 3 years of membership, to become very knowledgeable about the lives of the users, as well as providing a forum for review of his ongoing work. The group had no difficulty in recognising the speculative, long-term nature of the work and was happy to be involved even if there was little likelihood of immediate benefit to themselves.

Following on from this, the research team organised a more formal event, designed to draw the user group into the project. The event started with a video, compiled by the team, which used material from documentary and fictional sources to focus on aspects of natural movement, artificiality, relationships between people and their prostheses, representations of part human/part machine beings in fiction and self-image. This was the starting point for a discussion of the way that users related to their prostheses and of their aspirations. The second half of the discussion started with a presentation of the test-rig model of a naturally articulated hand which the team had produced and the group were encouraged to discuss the potential for entirely new designs of prosthesis. In particular their views were sought on the relationship between functional and cosmetic values.

The aim of this event was to use creative activities - compiling a video and making a model hand -as a stimulus to reflection and discussion which could then be analysed by the research team. A video was made of the discussion and this was then viewed and discussed by a design review group who were able to clarify a number of issues and identify a specific new goal for the project. The video discussion was later transcribed and is available for more formal analysis should that be felt necessary, however the main aim was to help the designers to move forward in their understanding and this was achieved. People's experiences and opinions brought to light by the event are frequently brought into team discussions as aids to exploring or illustrating issues.

6. Qualitative review and the importance of real objects.

For this project to succeed it is important to use analytical, quantified methods to review the work, especially when working with people from a medical/technical background. However some central aspects of the work are clearly qualitative and there is a need for qualitative review methods.

The work with user groups is intended to address this need but there is another example of qualitative techniques which is interesting because it provides a very effective complement to quantitative methods - Many of the people who work with human limbs have a great deal of experience of manipulating the limbs of living people with and without disabilities. When seeking to find out how well a model limb matches the movement of the human original we discovered that such people were able to manipulate the model and give an immediate, direct and confident evaluation without reference to any data. They appear to have "learned" what the moving limb should feel like and can apply this learning directly.

At various times elements of the design have been evaluated in this way by a medical physicist who specialises in wrist movement and a surgeon who works with elbows. If either person had been presented with a theoretical design in the form of drawings and/or a mathematical description, they might have been able to say whether that design would perform appropriately. However, it is likely that this would take a long time and they might have to refer to the same data that was used to create the design in the first place. Physical models provide an immediate method of evaluation which refers to a completely separate reference source (eg. the surgeon's memory of real limbs).

The models were produced skillfully to a good level of accuracy and were robust and easy to handle. This is a natural approach for a skilled designer and maker but the same skills, and interest in quality, are not evident in some "scientific" environments. It is therefore suggested that a model may be "worth a thousand pictures" but only if it is produced with some sensitivity.

A second example of the value of physical models arose when the first model hand was shown to a commercial manager from a company who manufacture prostheses. The person concerned was not an engineer but he had a general knowledge of manufacturing and a good understanding of the problems of cost and logistics associated with these products.

His first reaction was that the design was interesting but looked extremely complex and expensive to produce. He continued to examine the model for a one or two minutes without being prompted and stated that he had changed his mind as he could see that the apparent complexity came from a modular construction which was simple at the component level and could be made by low-cost moulding techniques while allowing a range of permutations of size to be achieved. Again, this information could have been explained through text and drawings but it is unlikely that the implications of this complex 3-dimensional object could have been appreciated as rapidly and clearly without a physical model.

This may seem obvious to experienced designers but it was remarkable to the design members of the team to discover that many of their colleagues in clinical engineering had no concept of the word "model" other than meaning some form of mathematical expression.

7. Outcomes

So far the project has produced a complete articulated arm model with analogous versions of all the joints of the real arm and hand from above the elbow, together with attachments and routing for most of the muscle/tendon devices which exist in the original. Qualitative and quantitative review is continuing but results so far indicate that the design is generally successful in providing a very close analogy to the original. The team will disseminate the technical outcomes and evaluation in a paper for a medical physics audience (Whiteley, Wilson & Rust 1999).

The design uses a modular approach such that individual "joints" and "bones" are relatively simple engineering components, suitable for production by precision casting or moulding, and it is expected that customisation could be achieved by simple fabrication techniques, perhaps suitable for local clinics. The aim has been to provide for a "Just in Time" production approach, using the "mushroom shaped" design philosophy described by Hal Mather (1988).

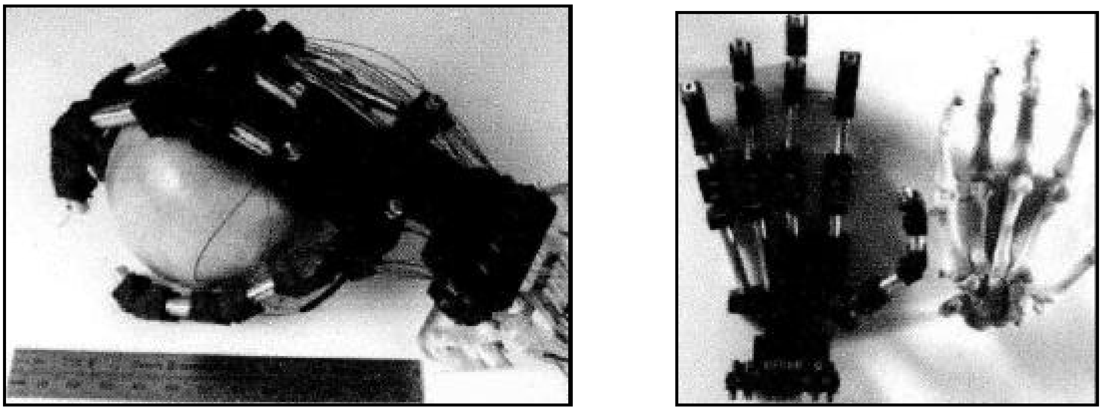

Fig. 8: First iteration of hand model showing modular joint construction

At present the design does not provide appropriate strength or weight and the forms of the components are relatively crude. One aim of the next cycle of development is to address these questions. It has been unusual for designers, used to the concept of producing pleasing objects, to be focused mainly on producing pleasing movement. However, having met the goal of realistic articulation, it is very important to ensure that the eventual prosthesis will have an appropriate appearance.

This raises some interesting questions since conventional wisdom in rehabilitation assumes that the goal of "cosmesis" is to reproduce the appearance of the original limb as closely as possible. However there is some anecdotal evidence that, as the technical quality of artificial legs has improved, some younger, more active users have been pleased to display their prostheses, perhaps as a form of prestigious technical sports equipment. This indicates the possibility of a very significant cultural development which the project team would like to explore before coming to any conclusions about the appearance and external design of a new arm prosthesis.

The outcome that has been recognised as most significant by most knowledgeable reviewers is the achievement of natural wrist rotation through the cooperative action of the two bones of the forearm with the elbow and wrist joints. This is completely different from the rotation achieved by existing prostheses which use a simple rotating mechanism at the wrist. Initially this raised as many problems as it solved since most users have amputations or congenital absences below the elbow and could not, apparently, benefit from a design which includes a functioning elbow joint. However the analogous elbow design offered an approach to a problem which the team had not, originally, intended to work on, that of attaching the prosthesis to the user (suspension).

The work with users brought out the finding that the most significant problem for many of them was the discomfort caused by existing methods of suspension. A breakthrough came with the realisation that, having developed a mechanical analogy for the elbow joints, it was possible to offset the mechanism without losing true motion, so that it could provide an external elbow mechanism, operating in tandem with an existing elbow and allowing true wrist motion as well as pointing to new possibilities for solving the suspension problem providing "tapered integration" rather than placing stress on the end of the user's existing limb.

Work is now proceeding, with the help of experienced users, to develop this into a usable elbow and attachment system.

A further development of the work is that the design for the elbow has been commended by a leading surgeon specialising in elbow replacement who has suggested that it could form the basis for a new design of implant, existing elbow implants being generally unsatisfactory because their design omits some significant structural elements.

8. Conclusions and Discussion

The project started with some principles and a very generalised long-term goal. The designers had no previous knowledge of prostheses and deliberately avoided adopting any existing techniques. They also avoided paying close attention to some of the recognised problems, such as suspension and "cosmesis", since they felt that these problems arose from the existing designs.

The only clear goal was to produce the closest possible analogy to the original anatomy. Otherwise the team relied on the use of a set of working principles to guide their work. These principles provided a set of questions which could be asked at any time rather than constraining the project to a specific series of tasks. At each stage there was a programme of work but the principles were the main aid to planning and changing the programme.

As the project progressed there were several points at which a pragmatic approach might have been used to overcome problems and move more quickly towards a usable product. However the designers believed that this would compromise the long term success of the work and lead to products which would be not be very useful and would not provide a development path for future designers. They felt that the unsatisfactory state of existing products, and the lack of any substantial development for many years had arisen precisely because today's designs are based largely on principles developed during the 1960's at the time of the Vietnam War and Thalidomide, under pressure to achieve quick results.

The team believe that their approach has been justified since there have been a number of recent unpredicted benefits from the work, for example the interest in adopting joint designs for surgical joint replacement and especially the opportunity to develop an entirely new suspension system. It is interesting that the project was criticised by one referee in its early days because it did not set out to address the problem of suspension, which was seen to be the principal problem with existing designs.

This project has demonstrated that a completely fresh start with a creative, principled experimental approach can bring benefits in a situation where a developmental, goal-driven approach may not yield significant results. It is arguable that, in this case, the existing technology has reached a developmental plateau and a radical approach is called for. The art of recognising the point at which established approaches are no longer productive may be the most difficult challenge facing managers and designers in any established industry.

The act of making something new changes the environment - it stimulates ideas and discussion, demonstrates possibilities and promotes understanding. Designers can make a unique contribution to research by creating things which allow other people to see the world differently and demonstrating this has been one of the most satisfying aspects of the project.

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