Experimental Design: Design Experimentation
Ashley Hall

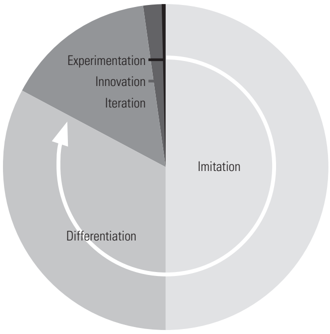


Figure 1
How the world is made

Industrial Design Experimentation

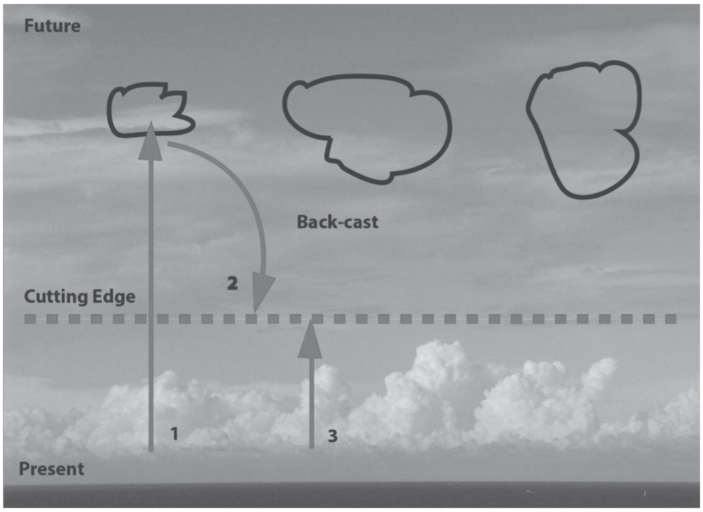
Creativity and experimentation are often considered to be core elements of the industrial design process. The diagram in Figure 1 shows the increasing levels of creativity, experimentation and risk associated with industrial output, ranging from imitation to experimentation. We see that a large amount of design necessarily consists of the reproductions of essential commodity items, including nails, screws, bricks, bolts, and other universal artifacts. Further up the scale, products start to become differentiated to have some market appeal. Iteration ensures that continual incremental improvements are made to enable increased performance and to keep pace with functional and technological developments. Innovation launches "new to the world" products, while experimentation sits at the very frontier of industrial output by proposing "future" offerings.

An alternative method of situating experimental design is to see it in terms of three five-year phases of technological development. In the first phase, products that will be available in the next five years are on the market but very expensive and often in alpha or beta development formats. Second phase products are working as test rigs in research and development laboratories and are not yet reliable or developed enough to be commercially launched. The third phase products, projected for manufacture in approximately 15 years, can be described by scientists and technology forecasters and may have some initial benchtop test-rigs or feasibility studies but in the main remain theoretical. Experimental design sits largely in the second phase, where outputs can be focused and developed through commercial application routes to market.

The effectiveness of design thinking is continuing to draw designers into progressively earlier and more fundamental phases of product evolution. A new model of parallel, interdisciplinary collaboration, where scientists, designers, and engineers work concurrently, is replacing the old model of science, to engineering, to product development. Instead of being given a technology "space package" to encase, designers in progressive organizations are often to be found at the forefront of new product generation.

The phrase "experiment" is used widely in industrial design, and yet it was surprising to review industrial design literature to find very few discussions of the strategic role of experimentation in

Figure 2
Blue-sky commercial model



creativity and in a comprehensive design process activity. However, examples *were* found in design education[1] (these will be discussed subsequently) and in design engineering, where the application of scientific methods to technical problem-solving was the focus.[2, 3]

To create new and innovative products, systems, and solutions, designers need to find the edges. These edges exist in two different locations; I call them internal edges and frontier edges. Internal edges define the problem spaces and opportunities that have been opened up by a variety of situations. For example, the rapid pace of industrial development has left some routes unexplored, or changes in current situations suggest a re-visiting or combination of historical solutions. These situations generate internal edges. Frontier edges are those that look beyond the current supply of industrial output, and they attract more ambitious designers. Theses edges are continuously moving forward as a result of advancing technology and product outputs, although the pace of the movement is not uniform; it can accelerate during a boom and slow down or even stagnate during a period of economic downturn. Experimental design projects have a dialogue with the location of the leading industrial edge, and they seek to move beyond it, to propose new solutions that can focus and evolve technologies, markets, user expectations, and behaviors.

An interesting comparison can be made between experimental design and "blue-sky" thinking, as practiced in a commercial context (see Figure 2). Designers in the present (1) are briefed to design a future product, that goes beyond current technology, market, function, typology, or a combination of these. The result (2) is analyzed through a process of "back-casting" to establish the future date of cutting-edge markets and technologies. Pinpointing this future date is part of the original briefing and is incorporated into the second. The second design brief (3) is formulated using the outcomes to propose a new product that delivers to the cutting

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1 Anthony J., Capon N., *Teaching Experimental Design Techniques to Industrial Designers*, International Journal of Engineering Education, 14:5 (1998): 335–43.

2 Anthony D. K., et al, *An Efficient Experiment Methodology to Investigate Product Design: An Acoustic Sounder Case Study*, International Conference on Managing Innovative Manufacturing, Aalborg, Denmark (2003).

3 Martin Tanco, Elisabeth Viles, Laura Ilzarbe, and Maria J Alvarez. "Manufacturing Industries Need Experiment Design (Doe)." *Proceedings of the World Congress on Engineering, Vol. II WCE 2007, July 2–4, London, U.K.* (2007).

edge of market and technology, factoring in design and development cycles. The overall aim is to deliver new products to market that maximize the criteria of market, function, technology, typology, and other specified attributes. Blue-sky projects have other valuable uses for planning the evolution of production lines, marketing, and sales channels.

Experimental design and blue-sky thinking share a similarity in pitching new concepts beyond the cutting edge of current production. The differences lie in the lower level of the initial industrial application focus for experimental projects and in the lack of a second strategic "re-briefing" stage to repurpose the results. Experimental projects can also have a pure design research motive.

Science vs. Design

Scientists and designers experiment in different ways. Scientists have been encouraged to build on one another's findings and knowledge to evolve their discipline. This goal has created an environment where experiments are necessarily peer reviewed and are required to be repeatable to be valid. Experimental design[4] ensures that a trajectory is plotted along which verification metrics can be established. Scientists know both where they are going and what they are looking for as a necessary action before they proceed. The process is convergent. Both Peter Galison and Thomas Kuhn give succinct insights into the drivers for scientific experimentation:

> In his 1962 work, *The Structure of Scientific Revolutions*, Thomas Kuhn assailed the universal adjudicating power of experiments, and therefore their independence from theory. Instead of arguing that observation must precede theory, Kuhn contended that theory has to precede observation… "As long as the celestial object later called Uranus was considered to be a star," Kuhn observes, "its motion was not noticed. Only when astronomers threw its identity in question could people 'see' it move".[5]
>
> Under normal conditions the research scientist is not an innovator but a solver of puzzles, and the puzzles upon which he concentrates are just those which he believes can be both stated and solved within the existing scientific tradition.[6]

Industrial designers, by contrast, have little motivation for their creative experiments to be reproduced because of the tendency for designers to value originality and uniqueness over reproduction of successful formulas. That designers are deliberately elliptical in their description of working methods and inspirations is widely observed. This stance has a range of reasons, one of which is to protect originality. Designers are experimenting to innovate. The problems with this approach are twofold: first, the increasing adoption

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[4] Peter Gallison, *How Experiments End.* (University of Chicago Press, 1987).

[5] Ibid.

[6] Thomas S. Kuhn, *The Structure of Scientific Revolutions*, (University of Chicago Press, 1962).

of design on a wider stage[7] has increased the density and size of problem types that designers encounter. Second, the convergent model of design, required by industry, focuses on near term design issues and discourages the investigation of more fundamental output. In contrast to the Thomas Kuhn quote relating to scientists, I would argue that designers need to begin solving problems that lie outside of their tradition.

Scientific experiments comprise a number of stages, from hypothesis or theory to experiment design, equipment, data, analysis, and conclusion, in a regular, linear format. In contrast, industrial design creative experimentation begins with a motivation that can be captured via a hypothesis but rarely captures the rigor and definition of the scientific equivalent. Experimental industrial design stages could be presented as: hypothesis, experimental phases, navigation, data interpretation, and exploitation of findings, often running in parallel. Designers use a variety of experimental tools that vary from abstract associations through to more controlled processes; such processes might include abstraction, abduction, subduction, concept generation, brainstorming, free association, and de Bono's six hats.[8] In practice, experimental tools are deployed for a number of reasons, either as a planned phase of procedure or to solve unexpected problems that arise. Because of design's commercial operation, design processes interface with the commercial world and require phases and conclusions that can be timed and valued, either directly or indirectly. Industrial design is therefore largely practiced as a convergent rationalized process that plugs into experimentation as required.

Comparing the scientific desire for complete experimental control,[9] achieved by being able to adjust variables for optimal results, with design experimentation, where it could be argued that variables are often "soft" and beyond useful calculation,[10] shows that the two methods are again operating from opposite perspectives. Design experimentation, it can be argued, relies on experiential and innate abilities in combination with the variables, which can be usefully calculated in the pursuit of innovation. In other words, two parallel streams of processing combine for decision-making: the *empirical*, composed of technical, testable, proven data, alongside the *lateral*, which allows the unexpected and abstract thinking that combines findings into new forms. Both are essential structures for successful experimental design, and it is the care and construction of these inter-relating elements that leads to the creation of impressive outcomes. If design can be summarized as "thinking to make," then craft may be summarized as "making to think." Experimental design processes can move fluidly between making activities to allow the release of thoughts on the one hand and rational calculation of ideas to be tested by making on the other. The interplay between innate response and conscious calculation generates the critical balance that allows for the progression to new discoveries. In design, lack

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[7] Bruno Latour. "A Cautious Prometheus? A Few Steps Towards a Philosophy of Design (With Special Attention to Peter Sloterdijk)." *Keynote Lecture for the Networks of Design meeting of the Design History Society, Falmouth, Cornwall, 3rd September 2008, Sciences-Po* (2008).

[8] Edward DeBono. "Six Hats Thinking." In *Six Thinking Hats.* (Boston, MA: Little, Brown and Co.,1985).

[9] Ronald A. Fisher, *Statistical Methods for Research Workers.* (Edinburgh: Oliver & Boyd, 1925).

[10] Donald T Campbell and Julian C. Stanley. "Experimental and Quasi-Experimental Design for Research." In *Experimental and Quasi-Experimental Design for Research.* (Houghton, Mifflin & Company, 1963).

of complete experimental control (in the scientific sense) is not only to be expected, but is to be desired. The lack of control brings into play other coping strategies that organically lead to innovative combinations, insights, and synthesis. An argument could be made that original design research is problematic because of the heavily applied nature of the discipline. This author has interpreted original design research as that which seeks to explore and extend fundamental questions of industrial design without the focus, drive, or motivation of user-inspired scenarios.

Scientific experimental design often seeks to average over noise and inconsistent data in order to give a reliable and safe result. For example, the Bayesian theory[11] of averaging over a sample space describes such an approach. Scientific experimentation therefore seeks to eliminate inconsistency whereas industrial design often looks towards the inconsistencies, aberrations, and other outlier characteristics to exploit through lateral, non-linear, and other creative processes. In design experimentation, therefore, the inconsistencies and unexpected findings are what often lead to innovation—a kind of "sensitive *exploitation* of initial conditions," to repurpose the chaos theory mantra.[12]

Pedagogic Model

A review of pedagogic design experimentation literature uncovers some interesting examples of an experimental studio based on digital and analog processes and the teaching of experimental design techniques to industrial designers.[13] Mathews and Temple focus on recursive iterations of creation and visualization in digital and physical media and the relationship to students' creative processes. This sophisticated method explores the alternate digital versus physical creative process model and finds both similarity and parallel design thinking. Anthony and Capon, by contrast, introduce scientific experimentation techniques to industrial design students through the construction of paper helicopters and use empirical

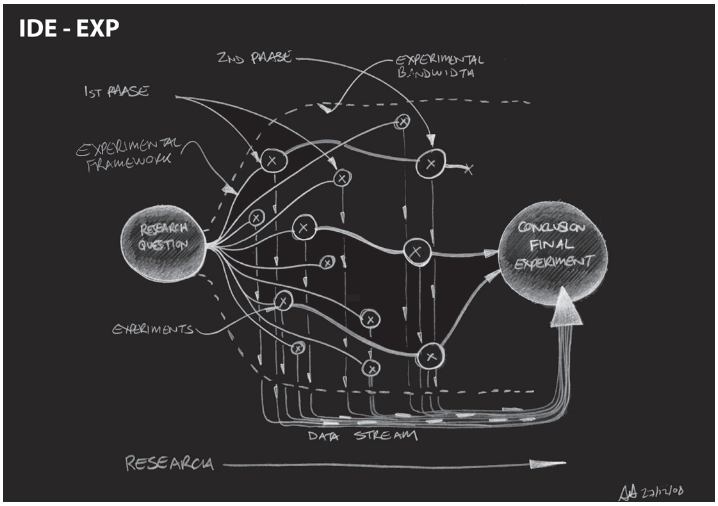

Figure 3
Experimental design meta-model

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[11] Kathryn Chaloner and I. Verdinelli. "Bayesian Experimental Design: A Review." *Statistical Science: Institute of Mathematical Statistics* 10:3 (1995): 273–304.

[12] R. L. Devaney, *An Introduction to Chaotic Dynamical Systems.* (USA: Addison-Wesley, 1989).

[13] Anthony J., Capon N., *Teaching Experimental Design Techniques to Industrial Designers*, International Journal of Engineering Education, 14:5 (1998): 335–43 .

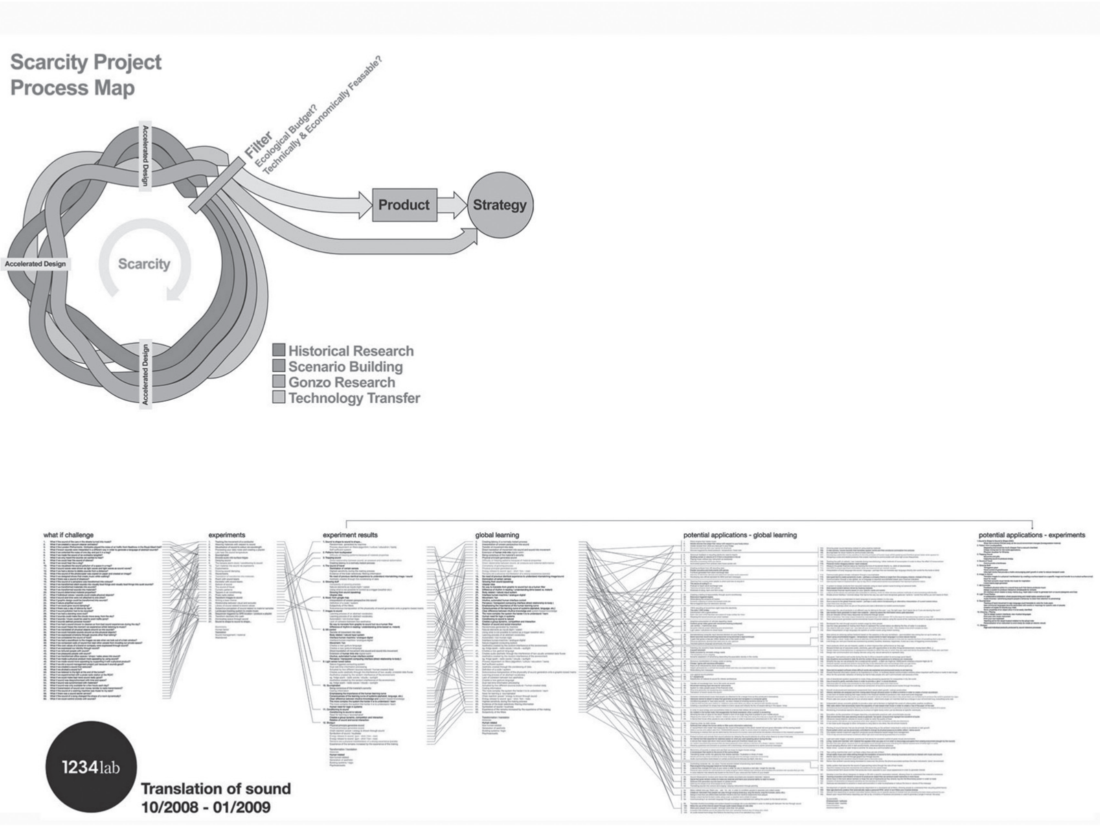

Figure 4
Experimental process mapping structure, Scarcity and 1234lab

scientific data to record and analyze the results. Contrasting these papers demonstrates the breadth of experimental design potential in design education, although, again, it was not possible to source research dedicated to the positioning of experimental design as a comprehensive industrial design activity.

A new experimental pedagogic meta-model has been developed for the Royal College of Art & Imperial College London's Innovation Design Engineering (IDE) dual masters degree program.[14] A diagram visualizing the model is proposed (by the author) in Figure 3. It treats the entire design process as experimental and is based on equal parts of research, science, and design methods. The process aims to balance the experimental breadth suggested via a hypothesis or research question to an initial range of experiments. The method treats an initial hypothesis as a description of the bandwidth or spectrum across which an initial set of experiments is used to explore the breadth of the proposal. Subsequent phases of experimentation develop and expand the findings of the previous phases with reference to the hypothesis. A final conclusion can vary from an exposition of the experiments and results discovered along the way to a final concluding experiment that sums the initial findings. During the entire process, a stream of data is captured that allows analysis of the results of each phase of the experiments and builds to the final conclusion. This model is in contrast to the conventional industrial design model, which emphasizes straight-to-market suitability. Outputs from this process have attracted investors, who

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[14] Ashley Hall and Peter Childs. "Innovation Design Engineering: Non-Linear Progressive Education for Diverse Intakes." *International Conference on Engineering and Product Design Education, September 10–11, University of Brighton, UK* (2009).

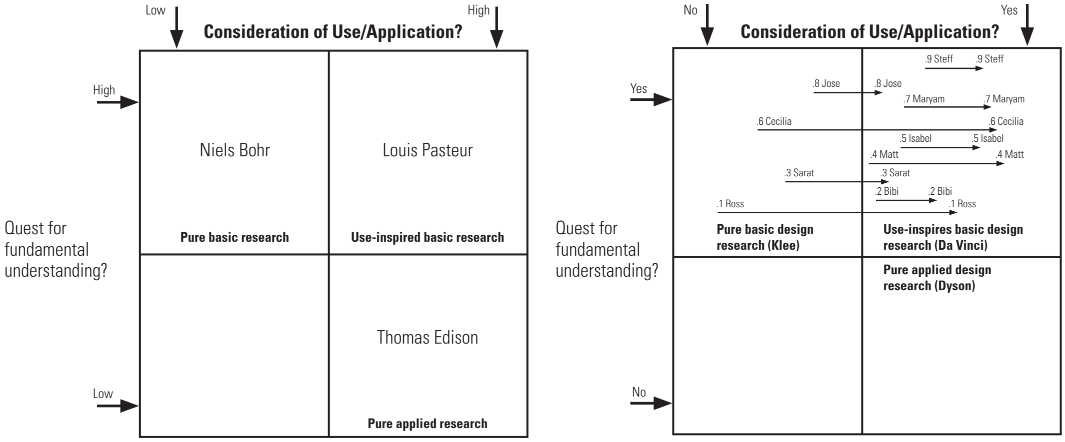

Figure 5
Pasteur's quadrant and experimental design trajectory

have funded second-stage feasibility and commercialization, with a view toward industrial production. It repurposes experimentation as an entire industrial design process rather than as selective elements within it.

The process mapping from two IDE group projects in Figure 4 demonstrates the capacity of the model to cope with both linear and non-linear[15] design processes for experimentation. The 1234lab group developed an experimental model based on noise that began by asking a series of "what if…?" questions; these questions were then filtered and further developed a number of times in an iterative reductive model until a final set of three main experiments were carried out at the project conclusion. In contrast, the Scarcity group developed a multi-layered cross-connected model that allowed experimental narratives to be informed by a sophisticated relationship of project aims and inputs in a non-linear format.

Figure 5 shows a diagram, created by this author, that compares Pasteur's quadrant of scientific research[16,17] to the level of abstraction and application in postgraduate experimental design projects. Pasteur's quadrant separates scientific research into four quadrants, based on the relationship between the quest for fundamental knowledge and considerations of use. Niels Bohr and Thomas Edison occupy the pure and applied research zones, while Louis Pasteur, having both applied and pure motivations and outputs, occupies the middle area. The fourth quadrant, representing no quest for understanding and no consideration for use, is empty.

The diagram in Figure 5 uses the same experimental basis as developed by Stokes but superimposes design research experimentation. The Bauhaus master Paul Klee exemplifies pure basic design research, with use-inspired basic design research exemplified by Leonardo Da Vinci and pure applied design shown by James Dyson. Student projects were mapped onto the quadrant depending on the trajectory shift from basic to applied design research during the evolution of the project. Observe that four students (1, 3, 6, 8)

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[15] Ashley Hall, "Context and Cohabitation of Linear and Non-Linear Systems in Design." *International Association of Societies of Design Research Conference, Seoul, Korea* (2009).

[16] Donald E. Stokes, "Completing the Bush Model." In *Pasteur's Quadrant.* Basic Science and Technological Innovation ed. (Washington, DC: Brookings Institution Press, 1997).

[17] H. Borgdorff, "Artistic Research and Pasteur's Quadrant." *GRAY Magazine, Gerrit Rietveld Academy, Amsterdam, Netherlands*, Issue 3 - Special Artistic Research (2007): 12–17.

Figure 6
Ross Atkin, Entropy Machine

began with an abstract, "pure basic design" hypothesis, where an eventual application was unclear or missing. Another five began their experiments in the "use-inspired" quadrant and gravitated toward the pure applied. The trajectories are created via a comparison of whether the hypothesis describes a pure basic design focus or user-inspired basic research. The ends of the trajectories measure the distance moved toward an industrial application. Pure applied design research (blank quadrant) is conducted via the design-for-manufacture learning strand on the IDE course and is not considered here. In the scientific model and literature descriptions, patterns of operation appear to be confined within one of the three occupied Pasteur quadrants. To an extent, this observation might be expected because of the tendency of industrial designers to be application led or application seeking, even when investigating fundamental questions.

The process adopted for the pedagogic experimental design model comprises elements of scientific, research, and design methods. Scientific methods are adopted for the rigor of detailing outputs and designing and conducting individual experiments. Elements of research methods are used in the construction of a hypothesis or research question and in the continual comparison of findings, as well as in a significant project report detailing all the phases of work and the narrative trajectory leading to the final conclusions. Design methods come into play via the selection of experimental ranges and creative interpretation of results to move the exploration forward.

Case Studies

A selection of three case studies described here shows the results from the pedagogic experimental design model. The projects were all individual postgraduate work undertaken over a five-month period on the Innovation Design Engineering Experimental Design strand in 2009 and exhibited at the Royal College of Art summer show the same year.

Case study 5.1. Ross Atkin's "Entropy Machine" is inspired by the second law of thermodynamics and the way nature "gets around it."[18, 19, 20] The aim of the experimentation was to physically simulate chaotic natural phenomena and the manner in which they can give rise to ordered structures (at a scale easily comprehended by viewers). The showpiece uses a rotating sphere with uneven inner surface and a number of geometrically "programmed" solids with mating surfaces. As the sphere is spun quickly, the solids disperse

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[18] P. W. Atkins (no relation), *The Second Law.* Arcadia ed. (London, UK: Samuel French, 1993).

[19] I. Prigogine and I. Stengers. *Order Out of Chaos: Man's New Dialogue with Nature.* (London: Heinemann, 1994).

[20] A. G. Cairns-Smith, *The Life Puzzle: On Crystals and Organisms and on the Possibility of a Crystal As An Ancestor.* (Edinburgh: Oliver & Boyd, 1971).

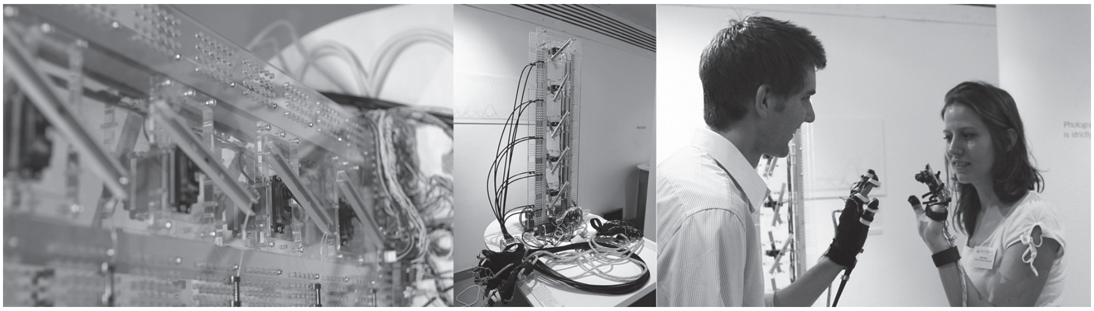

Figure 7
Matt Johnson, Symptoms of the Self

into single units around the circumference, mixing together. A second slower cycle engages, during which the solids agglomerate into discrete clusters of similar type, effectively un-mixing. Various iterations of forms, tumblers, rotation speeds and cycles, and mating notes were tested. Future uses include self-assembling products and self-sorting packaging for recycling or reuse.

Case study 5.2. "Symptoms of the self" (see Figure 7) by Matt Johnson investigates proprioception and body schema[21, 22, 23] in an experiment to uncover new ways for the mind to map the functions of the human body. Based on leading-edge psychology research, a machine was constructed in which a pair of gloves worn by a user maps three-dimensional movement in a sensor glove that transmits an equal force to a second driver glove worn by the second user. The resultant effect questions the mind's image of the body schema by ceding control of the hand to another user. The effect can be further reinforced by programming a delay or a reverse to the driven hands, thereby challenging the psychological conception of body composition, relationship, and function. Future applications beyond the questioning of body schema include the learning of "expert" dexterity required by a musician or for craftsmanship.

Case study 5.3. Sarat Babu's "Microkinetics" (see Figure 8) explores micro-level structures[24, 25] embedded in a matrix that produces physical characteristics outside of the expectations of their three-dimensional forms. A combination of selective laser addition (SLA) rapid prototyping and cast polyurethane and silicon allowed the creation of an "alphabet" of micro functions, as illustrated in Figure 8. The image on the left shows the alphabet samples while the image in the middle shows a hexagonal section that swells in the center when twisted in one direction and shrinks when rotated in the other. The image on the right shows a structure that deforms resulting in two even bulges on one side of the surface when the ends are pulled evenly. The experimental output has applications to a wide range of intelligent dynamic structures at the macro and molecular level.

Conclusion

An exploration of the structural differences between scientific and design experimental activity has shown considerable differences of

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[21] V. S. Ramachandran, D. C. Rogers, and S. Cobb, "Touching the Phantom." *Nature*, 377 (1995): 489–90.

[22] S. Blakeslee and V. S. Ramachandran, *Phantoms in the Brain*. (London, UK: Harper Perennial, 1998).

[23] M. MacLachlan, D. McDonald, and J. Waloch, "Mirror Treatment of Lower Limb Phantom Pain: A Case Study." *Disability & Rehabilitation* 26 (14–15) (2004): 901-4.

[24] S. Hanna and H. Mahdavi, "Modularity and Flexibility at the Small Scale: Evolving Continuous Material Variation with Stereolithography." *University of Waterloo School of Architecture Press, Toronto, Canada* (2004).

[25] S. Hannah and H. Mahdavi Siavash, *An Evolutionary Approach to Microstructure Optimizations of Stereolithographic Models*. Proceedings of CEC2003, 2003.

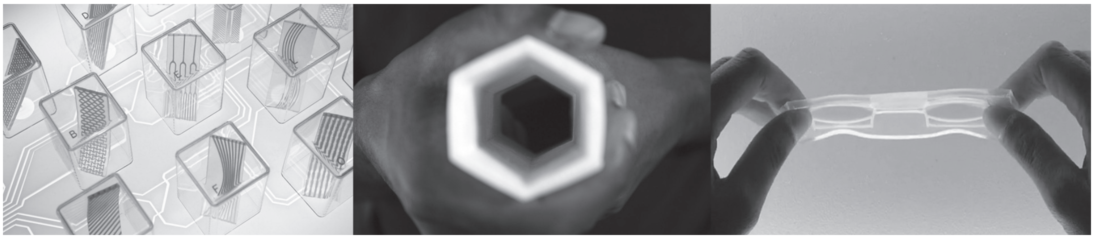

Figure 8
Sarat Babu, Microkinetics

outlook, motivation, and methods. In many ways, these findings demonstrate strong contrasts and in some instances polar opposites in terms of operation. The proposed new model for complete experimentation as an industrial design activity—including design, research, and science methods—aims to answer the increasing movement of designs into earlier and more fundamental stages of product and technology formulation. Only time will tell whether this trend continues and whether the model developed becomes part of this activity. Case studies from the experimental pedagogic model illustrate the breadth of potential investigations—from materials exploration, to the interface between psychology and body image, to the re-application of fundamental laws as creative tools. The outputs show signs of fundamental design innovations after following a whole design process model. Although the Experimental Design strand of the IDE masters is still in its early days, the number of projects being commercialized from it through business incubation centers, as well as the angel funding these projects are attracting, demonstrate some successes.