The impact of modular product design on innovation compared with design from first principles

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Abstract

The research looks at whether modular design methods can compromise innovation when compared with design from first principles. The questions that the authors investigated were: to what extent does modular product design restrict innovation in design? Is design from first principles a better starting point for innovation, and if this is the case, then what methods and environments facilitate design from first principles among design teams? The authors were also interested in the relationship between industry and academia when taking these differing approaches.

The authors consider design from first principles to be where there is a significant shift in a product or system which - while addressing similar societal wants, needs and desires - is not built upon nor based on previous technological modules, or on existing design paradigms. These shifts derive from “tabula rasa” design research and lateral thinking, often in combination with new technologies or innovative technological combinations. These innovations are radical as they force creative and/or technological discontinuity.

Informed by their projects with industry and academia, the researchers argue that modular-based physical products are generally more appropriate for evolutionary designs or mature products, and that a design from first principles approach is better suited to genuine innovation and step change design. However, in terms of the creative design process, a design from first principles approach can be accommodated in both modular and non-modular products or systems.

Keywords

Modular design; industrial design; design education; design innovation; design methodology

Through action-based research case studies of collaborations between industry and academia, and an industrial case study, this paper considers the pros and cons of design from first principles versus modular design for products. The differences relate to both the design methods employed and innovative outputs that result, as well as the design thinking.

Objectives

The objective of the research was to undertake and review a number of case studies to investigate the impact on innovation of modular design methods versus design from first principles methods. Another aim was to investigate the relationship between academic design teaching and industrial collaboration, and to see how the teaching process could be improved and better orientated towards practice-based requirements through one approach or the other. A final objective was to determine the extent to which process (design thinking) predetermined the format and success product outputs.

Research proposition

The framework for our work emerges from the view that the rationale for component based design is well established in manufacturing (Dahmus, 2001). Modularity can produce cost savings on tooling, assembly and maintenance, improve quality and reduce design cycles. However, this consolidation and organization can mitigate innovation (Senge, 1990) for example for 'green' auto design. This notwithstanding, the software industry has achieved phenomenal improvements in innovation, productivity and quality through the adoption of object-based modular programming over the last 25 years (Sutherland, 1999). But it is difficult to apply physical design methods that correlate with software modularity methods (Gabriel, 1998). Modular strategies appear to allow for, what may be called 'significant' improvements ; it can be argued these alone may not assist greatly in developing step change innovations.

The research proposition here is that modular design methods could compromise innovation compared with design from first principles. In this context, the research questions were: (1) to what extent does modular product design restrict innovation in design; (2) s design from first principles a better starting point for innovation, and if this is the case, then what methods and environments facilitate this among design teams? For this research, the context was design as artefact-based industrial design, conducted in teams - typically with a technological component. We present the following case studies:

- **Unilever** project which had successfully created paradigm shifts in a product range.
- **3 mobile** case study demonstrating that design from first principles is able to contribute to 3 Mobile's future phone design thinking.
- **Swarovski and Sharp solar** project that used a modular methodology coupled with a second stage using design from first principles.
- **McLaren Group** case study where they employ more subtlety to the distinction between modular design and design from first principles

The themes that resonate within these studies highlight relationships between issues and design processes as they relate to Modular design, Design from First principles, and 'Step Change' innovation. In order to contextualise these issues we first discuss what is meant by modular design and Design from First Principles.

Design Methods

Design from first Principles

The authors consider design from first principles to be where there is a significant shift in a product or system which - while addressing similar societal wants, needs and desires - is not built upon nor based on previous technological modules, or on existing design paradigms. These shifts derive from "tabula rasa" design research and lateral thinking, often in combination with new technologies or innovative technological combinations. These innovations are radical as they force creative and/or technological discontinuity, and they are similar to the discussions in the technological change literature where they address the notion of S curves and discontinuity and the importance of it (Girifalco, 1991) (Porter, 1980 and 1991).

The web has greatly helped make innovative "learning how to learn" (Senge, 1990) methods more realistic. Thomas Edison (Josephson, 1992) stated that it took 100 days to become a sufficient expert in any area to permit invention – with the internet, this was reduced dramatically. With a deep understanding of first principles and how these may be applied in alternate contexts, teams could methodically and creatively apply information. Without this, technology information did not equal technology, or for that matter new highly innovative designs (Porter, 2005).

Modular Design

Modular design can take the form of physical hardware components or software, or a mixture. This paper is not concerned with the notion of modular design that relates to the ability to add products together for consumer benefit. It is concerned with the design of products by selecting and using existing components or assemblies to build a new product. Such a product may still have original parts or the parts may be scaled to some extent physically. Components and assemblies can be manufactured in-house, or sourced from suppliers.

Modular design is considered to be fundamental to the computer industry and software in general (Clark & Baldwin, 2000). Software modularity is generally the only way of writing contemporary code - with exotic exceptions such as neural networks. The authors acknowledge the crossover influence of software systems design methods into product development (Gabriel, 1998).

There are examples of physical product manufacture where modularity has been embraced that have an evolutionary approach to new product development. One of these is the automotive industry, where the approach increasingly extends outsourcing to modular consortia (Collins & Bechler, 1998).

Research Investigation

For experimental results, the authors reviewed pedagogical and industrial projects. A number of projects undertaken by the authors were reviewed as case studies for the research. These were academic-commercial case studies and interviews. Four of these are described.

Case studies

Academic-commercial projects

The academic-commercial projects were commissioned by corporate clients and undertaken by students at the Royal College of Art, a postgraduate Masters course that takes students from a range of backgrounds: industrial design, engineering and science, materials, architecture, marketing, business. The focus of the course is collaborative working.

Unilever

This 2006 case study relates to a commission by the international food, drink and household products company Unilever. The project was for a team of 15 graduate students to come up with new formats for ice cream. Unilever is the second largest ice cream manufacturer in a global $59bn industry (Scott & Flanagan, 2007), holding 16% of the market to Nestlés 17.5%. However, most of Unilever's market share has been through aggressively expanding through acquisition of established brands such as Ben and Jerry's in 2000. Although this was a successful strategy, growth was not coming from in-house ice cream innovations to the extent that such a large business required. Generally, previous innovations related to maximising the variations that could be offered by existing brands and product components – the ice cream industry's equivalent of incremental and modular design. So the project was brought to the Royal College of Art by Unilever's R&D and marketing departments to see how design from first principles from a group of mixed discipline students could lead to innovative product concepts.

To facilitate the ideas generation, an unusually formatted brainstorming day was held which blended concept design methods with marketing aspects. Participants came from Unilever to join the graduate students. The format started without any assumptions and went back to the principles of what being an ice cream means. The session is summarised below.

- **I am an Ice Cream**

  One by one everyone describes themselves (what kind of ice cream are you...). When am I liked when am I not liked? When am I allowed, not allowed? What people like me, who doesn't? How am I different? Where am I liked where am I not liked? How am I liked how am I hated? These become some of the catalyst for 'What's the Problem'.

- **What's the Problem**

  Format: for this, once the problems are written down, sketch doodles only are made. The groups brainstorm problems by noting them down on blank cards which are then shuffled between both groups and redistributed "blind". The groups work on solutions sketching lots of possible ideas. Example: A problem is that ice cream melts in a fridge (as opposed to a freezer); so solution may include a "high temperature" ice cream (like yoghurt).

- **Speed date**

  Each group shares out the designs among the team (one idea per team member) and then these are speed date presented as 1 minute per idea one-on-one to each of the other group members. Everybody hearing an idea has to find 3 ways of improving it. These should be noted on the drawing.

- **Killer Rabbit**

  A positioning statement is made and then the groups come up with the designs backwards from this point. What would have happened in 1989 if you had been asked to design an iPod? Example: Positioning Title: Global Hypercolour; Positioning Statement: a kaleidoscopic ice cream that reflects the national colours, the time of day, or the mood of the user. How to: illustrate how it could work..

- **Run the Gauntlet and wrap up**

  Selected work is presented and discussed at a final ideas review.

The brainstorming generated a number of ideas that appealed to Unilever and these were subsequently developed by the graduate students. Although the work was confidential, it can be revealed that none of the ideas had any relation to existing ice creams on the market. Two of the ideas were taken on by Unilever for subsequently bring to the market. Unilever was delighted with the result which had successfully created paradigm shifts for their product range.

Hutchison Whampoa's 3 Mobile

In this 2007/8 case study the mobile phone company 3 Mobile, owned by Hutchison Whampoa, commissioned a group of 30 graduate design students from the Royal College of Art in London to respond to two briefs. The two briefs were: (1) design the best phone ever for today, and (2) design the best phone ever for the future. The company made losses in 2008 of HK$3.2bn on global revenues of HK$32bn, with a customer base of 19 million people worldwide (Middleton, 2008). These losses were large and the company had lost money since launching with 3G phones in 2003. When 3 Mobile briefed the graduates on this project they observed that they had launched with 3G too early for customers and with phones that were complicated and had too many features.

The purpose of coming to design graduates was to see if they could get a fresh and innovative approach to their future phones. 3 Mobile had identified the market as moving towards specialist phones which offered features related to websites, particularly social networking sites. Hence, they were looking at a Facebook phone and they had already launched a Skype phone offering free calls Skype to Skype. The approach taken by 3 Mobile prior to this graduate design commission was that early 3 Mobile products attempted to incorporate as many general purpose functions as possible.

The commission to the students was looking very much for a “design from first principles” approach. The results of the work were richly varied and the designs were of great value to 3 Mobile in terms of provoking their own design teams’ thinking. Additionally, several concepts had aspects which 3 Mobile felt they could develop into real products. A question, not covered by this paper, is the extent to which outsourcing of detailed phone design impacts on 3 Mobile’s product success.

This case study does demonstrate that design from first principles was able to contribute to 3 Mobile’s future phone design thinking when undertaken as an academic collaboration, at least complimenting the in-house process. The award of the contract to the Royal College of Art was made at a time when 3 Mobile had moved away from the modular, scaleable feature-rich product model. Figure 1 shows some of the phone designs from the project. Note that several design anticipated subsequent commercial products: “Free Key” anticipates the Blackberry Storm with a flexible LCD button surface; the “Teiko” phone anticipate kids’ phones; “Touch” the rise of gesture-based interfaces.

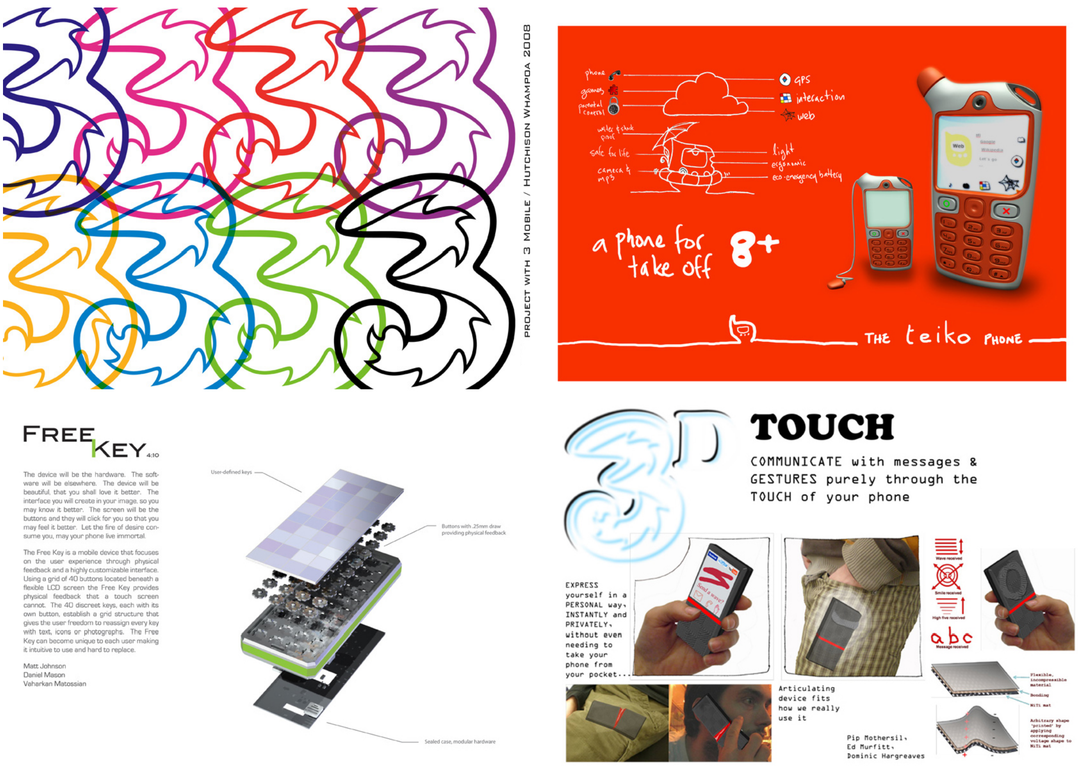

Figure 1: “design from first principle” mobile phone concepts for 3 Mobile, 2008.

Swarovski and Sharp Solar

In 2008, Swarovski Crystals sponsored this project for graduate designers at the Royal College of Art. Over 6 weeks, the project was co-run with Lovegrove R., an internationally recognised industrial designer with expertise in advanced materials and solar design, and The project received technical support, equipment and materials (photovoltaic solar panels and wafers) from Sharp Solar. The project brief is summarised below.

- *Located in the near future, and on the outskirts of a Northern European city, Sunny delight will be home to a few lucky residents who will benefit from a town that uses the very latest solar power, and related technologies, to create the world's first ever integrated zero energy housing and transportation system. It is your job as cutting-edge designers to make Sunny Delight. The challenge is to create a vision for a near future that works seamlessly in terms of both design and technology.*

For this case study, there were two distinct stage to the project. An initial stage used a modular methodology and the second stage used design from first principles. Although the two parts of the project were in response to separate parts of the brief, the graduate students were the same and it offered some comparison between the outputs offered up at each stage.

An important first stage of the project was set up as a Skunk Works (Jenkins, 2001) using working hardware components and systems, for modular systems design:

- *Design and build something interesting in 48 hours with the solar and other kits that are provided. You can make whatever you like but it needs to be an experiment from which you learn (and can tell us about) to help you understand the technologies involved.*

The second stage of the project encouraged a holistic integrated innovative approach:

- *Individual team members will each champion one or more of the Sunny Delights components to resolve in more detail: house, garden / outdoor areas, car, car port / street, marketing / services, energy system, business / economic case. It may be that your design merges or redefines these almost beyond recognition. For example, you may drive a piece of your house into work!*

Although the Skunk Works stage resulted in some very interesting working experimental design test rigs, none of them offered a real step change in innovation. The combinations of solar hardware (all using photovoltaics), sensors, mechanics, and software resulted in some interesting ideas, but the real innovation came with the second stage of the project. For the second stage, the graduate students were not asked to follow a specific methodology although they were asked to work in teams of 3-4. The students had a free hand at how to interpret the brief. Some of the project results are shown in figure 2.

Interestingly, the projects in stage two moved away from variations on use of photovoltaic solar panels for energy supply alone, and looked at comprehensive integration, as well as alternative solar energy cycles such as ammonia and hydrogen from algae. Although these stage two projects were mostly created as non-working models and animated illustrations, the science and technology research to prove feasibility was done fairly thoroughly convincingly.

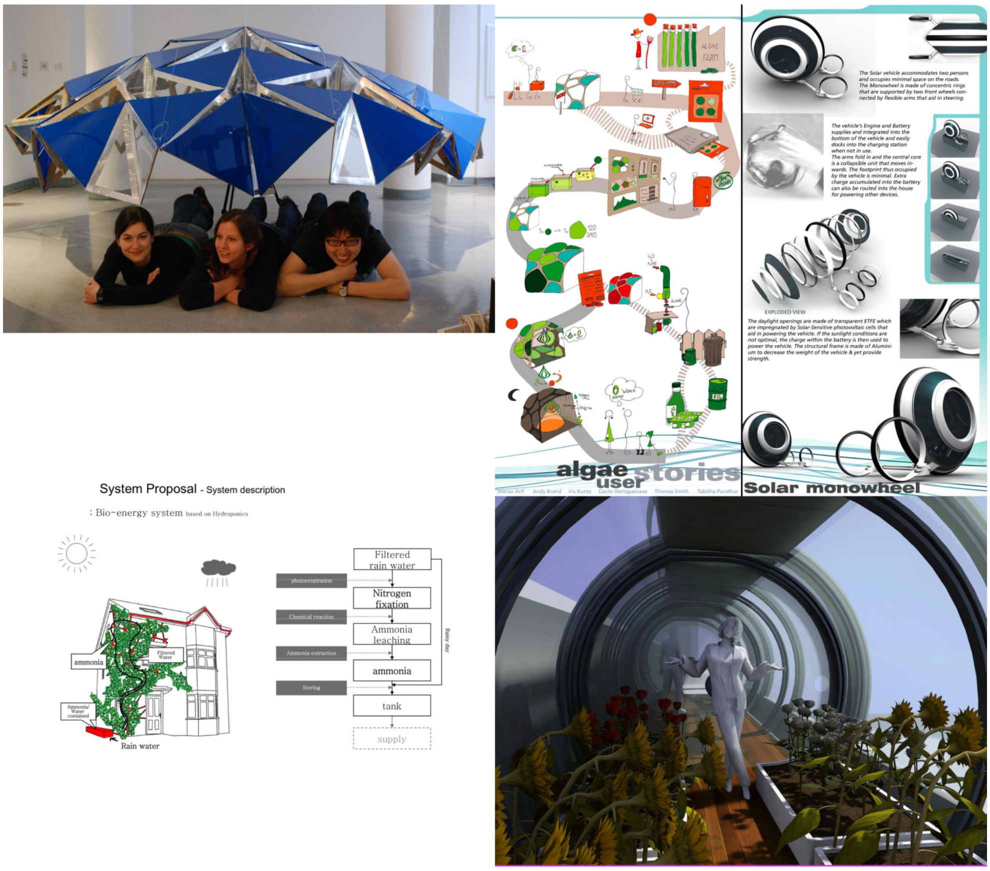

Figure 2: design proposals from ‘Sunny Delight: Solar Living’ a Swarovski / Sharp Solar project. Clockwise from the top left: a deployable solar shelter; Algae-based hydrogen solar cycle; a solar powered ‘wheel vehicle’; ammonia solar cycle; a hydroponic solar living unit.

Industry: McLaren Group

In 2009, Van Manen P. a CEO of control systems at McLaren Group the Formula 1 race team was interviewed. McLaren is currently contracted provide a modular, programmable electronic control system to all race teams in Formula 1, and this system is Van Manen’s responsibility. Previously, each race team designed and built their own control system, comprising sensors, computer and casings. Figure 3 shows the McLaren vehicle. McLaren are also contracted to develop high technology telemetry systems for other industries, including ranging public rapid transit rail systems.

Figure 3: McLaren Formula 1 racing car.

The interview with McLaren lent more subtlety to the distinction between modular design and design from first principles because, although McLaren create modular systems, their design thinking takes a more conceptual and design from first principles outlook when looking for innovation.

In the case of high technology electronics, systems are typically modular in nature, with microprocessors and other embedded circuitry forming parts of larger modular systems. The thinking required to develop these systems is far from being a simple reconfiguration exercise of mixing and matching modular sub-systems in order to develop a larger more complex system. This was evidenced in the McLaren interview. The McLaren electronics group rely on a few core guiding values for modular system design.

Firstly, in order to cope with the increasing technological changes that are advancing at an exponential rate a core understanding of the physical principles is imperative. In essence, when step change in design is required it can be argued that what is being manipulated is not mere components but the creative manipulation of divergent sometimes opposing physical principles. Secondly, McLaren’s designers (ie: design students) also need to understand which are the nonnegotiable parts of design or the semi-negotiable, if they are going to develop technologies even further in innovative ways. Thirdly, McLaren regard it as important to have confidence in one’s capabilities and a willingness to work together as a collective intelligence. When a high technology design team is working together they must see the relevance of what they are trying to accomplish and more often than not the divergent design specialists must communicate through a language of metaphor, where these metaphors relate to key physical principles not technological modular blocks. Fourthly, is an acceptance that what one learns today won't be the same as what is around in five years’ time. But that the underlying principles - first principles - will be the same. McLaren’s fifth and final value is the ability to have a vision and to develop a shared vision, because in talking about clarity of vision the ability to be agile and listen to others is key so they can operate with networking. This core principle not only relates to the physics but to the social dynamic as well.

When Van Manen is looking at a problem outside of his immediate area of expertise he will consider it in terms of metaphors. And as long as it is done with care he generally starts extending his knowledge into different applications and often new and innovative ways. It is important to understand a lot of this also comes back to the basics, because the better understanding one has of the basics, the easier it is to move between these metaphors. Because we can see the common elements and say “yes, I understand that now”. For example, a bigger battery is like starting up higher on the Hill, so it will flow longer and faster and that is clear now. And so we can start building our experiences and metaphors any time.

Van Manen considers that it is important to remember a lot of the innovation that people do is building things, building business, building technologies. This comes about by being able to collaborate to understand how things fit together. There aren't that many sort of light bulb inventions, there are few inventors, there are a lot more people who can see how things/principles fit together. Therefore, reasonable working knowledge of the general way in which the world operates, physical laws, chemistry, mathematics, are all viewed as being important when involved in any sort of technological area. This notwithstanding Van Manen assumes that if he talks to anyone within his organization that they understand the basic laws of physics so he does not need to explain to them if something is heavy then it would accelerate slower if a force is applied, so just basic ground knowledge of physical principles is very important.

One of the things that Van Manen observed from working in the motorsports industry and its environment is that he is certain that one of the reasons that we have such good engineers in motorsport is they get the opportunity to design something, make it and put it into service in a time frame which is short. And every time they make something they get better and better at making things. And they increase their confidence. They know when something's not going to work. They know if they are at a dead end and have to change something. It is strongly arguable that a successful educational environment should also embed the understanding that balance between theory and praxis, between making and doing, and thinking about making and doing is necessary.

The McLaren approach is that when developing a system, whether it is a machine, a business system, or whatever, the key element is to understand what it is there for. If one is clear what is there for and what the important outcomes for it are, then this can properly frame what the important characteristics of that system are that are allowing innovation to occur, even if a design team member does not understand all of it and does not have a big picture. Once one understands what the importance is, and identifies the important characteristics of a system, that then frames whether one breaks it down and analyses it, or whether one looks at how something flows through the system. This in turn assists in innovation development.

By way of example Van Manen suggests that if we take a transmission system of a car, asking what is the reason behind having an engine and a gearbox and a differential, the reason is so that you can apply traction at the wheels. So the complex systems are there for managing the delivery of torque. Once you start thinking of that as a torque manager, then you can focus on the engine as a source of torque for the gearbox and that it controls this torque. In this conceptual model, the reason that these things interrelate is just to manage the torque running from the combustion chamber to the wheels. Via a first principles perspective, it immediately gives you a way of thinking about the system and how you exchange the torque, and then an understanding of trade-offs in terms of mechanical advantage. When thinking about a power train in that way it always come back to the core principles. A McLaren designer ends up saying “what we are interested in is this torque, and how we dealing with the torque”, as opposed to starting from a classical engineering perspective which tends to be very modular in nature.

Discussion and Conclusions

Based on the case studies, the research findings indicated that a modular approach to industrial design is generally but not exclusively more appropriate for evolutionary designs or mature products, and that a design from first principles approach is better suited to genuine innovation and step change design. The case studies indicated that, when faced with the need for step changes in innovation industry-academic collaborations could bring particular value.

The role of academia in offering a step change approach to established businesses was apparent. Many companies are better suited towards steady state and incremental design changes, so the academic partnering can give opportunities for tabula rasa design approaches, possibly even more so than design practices which will have preconceptions through practical experience. The authors found that creativity and lateral thinking were able to make up for lack of experience among graduate students, particularly when mentored by experienced facilitators from both academia and industry.

The research also highlighted difficulties and challenges presented to corporations in accommodating the culturally different approaches of design evolution and revolution within a single design environment. Another finding highlighted tensions between a culture of formalised experimentation, as opposed to a more chaotic or intuitive one, as part of an innovative creative design process. Modular design was more likely to mitigate creative leaps, but these could also be compromised by homogenous use of methodologies.

In addition to the obvious requirements of a brief and a project plan, the research found evidence that there is merit in the adoption or adaptation of design methods to use as creative scaffolding in both education and practice. These can be bespoke, such as the unusual design-marketing hybrid method used in the Unilever case study, or established systems such as TRIZ (Orloff, 2003; Savransky, 2000) which have first principles at their core.

However, as evidenced by the McLaren approach of conceptual thinking and team working, design methods are not exclusively necessary for innovation. The McLaren case study also indicates that although the division between design from first principles and modular design may be explicit in terms of physical product, the method used to design the product does not have to follow the physical outcome. In other words: a modular product can be designed from first principles. The 'aha!' innovative moment (Gardner, 1978), is an important tool also. But the authors conclude that the frequency and quality of the 'aha!' increases within catalysing design methods in conducive cultures.

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