Product development methods: Leonardo Da Vinci versus modern engineering education*

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SUMMARY:

Modern methods for product development taught at mechanical engineering programs at Mälardalen University, Eskilstuna, Sweden, are compared with methods used by Leonardo Da Vinci. Similarities and differences are discussed and tentative conclusions are drawn on how to improve engineering ingenuity. Ideas on how to improve engineering programs towards an "Leonardonian" (insatiable) curiosity of the students attending the courses are also discussed.

It is concluded that the major development steps are more elaborate today but the general procedure is the same. E.g. the selection of the best concept is documented in a more rational procedure today than what is known about Leonardo's way of choosing concepts.

And we conclude that a *multiplicity of available tools* should be at the product designers disposal. The selection of tools is up to the designer and the design team and the creative "renaissance" *environment* should consist of *a mixture of art and science with an abundance of technological solutions at the designers disposal*!

We propose an engineering program curriculum inspired by Leonardo's "own university program". We also argue that a general picture of the behavior of a true *renaissance engineer of tomorrow* could be based on *The Seven Da Vincian Principles* conceived by Gelb, who has been inspired by the life and methods of Leonardo.

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1. INTRODUCTION

”Omniam mirare etiam tritissima” a Latin sentence meaning “wherever you look there is something worthy of a thesis”. These words coined by the Swedish 18th century scientist Carl von Linné (1707-78) could be used to characterize the 15th century renaissance inventor, engineer, architect, painter, sculptor, musician, philosopher … Leonardo Da Vinci (1452-1519). His insatiable curiosity planted many seeds to modern engineering products. The question is why was he so proliferate in generating new ideas and concepts and what can we learn by studying his behaviour – his methods of learning and problem solving. Are there hidden methods of creativity or is everything that Leonardo did already incorporated in modern product development methods?

First we will summarize modern engineering methods with focus on concept generation. Then we will learn about Leonardo’s methods, compare the methods and discus and draw conclusions among others on ideal product development methods and engineering programs curricula.

2. MODERN PRODUCT DEVELOPMENT METHODS

Ideas to innovative products or commercially successful products are not like bolts from the blue. In general they are the results of hard and persistent work and awareness of problems longing for to be solved by many people, i.e. problems with an inherent market. Either you are not aware of the design process steps you are going through or you try to work systematically and use whatever tools found to be useful in the design of new products. Of course the design process is not a linear process in the minds of the engineers or product designers but the design project has to proceed in a certain linear order. The project has to pass certain gates in order to solve the design problem within given deadlines.

In the education of engineers of mechanical engineering or innovation and product design at the department of IDP/MdH we use Mike Baxter’s book on *Product design* as a summary and model example for modern product development methods.

2.1 Opportunity specification – the heart of innovation

The key to commercially successful products, and therefore the heart of innovation, is to find a gap in the market or a new field for consumer products. We must be able to convince ourself/employer/investor that our product concept will have good enough chances to meet customer needs and find a market in spite of competitors and also gain a profit for those involved in the product development process. We must be able to make a crude estimate on how to realize the whole design process. This process is usually called a pre-study or a feasibility study.

The design steps we stress are:

1. Problem formulation – crude product specification
2. Product functional analysis
3. Concept design – generation and selection of concept
4. Embodiment and detail design – detailed product specification
5. Production, marketing and sales

Here we focus on the steps 1-3 to compare with Leonardo and make just a few comments on the other steps 4-5.

2.2 Concept design – the art of innovation

In the process of concept generation you can use whatever creativity tools you prefer to generate ideas e.g. brainwriting, brainstorming, SCAMPER etc (Baxter, p.61f) but as a seed for incubation and idea generation we strongly advocate product functional analysis. This is a tool to establish the main, part and supporting functions the product should fulfil independent of how you find a solution. The process of choosing the best concept is guided by a systematic 4 step procedure (Olsson, p.38f) ending with an evaluation matrix. See Table1 for details. We shall compare these design steps with Leonardo’s methods.

In the following two paragraphs we just make a few comments on steps 4-5. These steps will not be discussed further in part due to lack of knowledge of Leonardo's behaviour but mostly due to a firm conviction from the history of his life that these steps were not his peace of cake – after all Leonardo was not a business man!

2.3 Embodiment and detail design – the hard core of engineering competence

These steps, which also calls for idea generation!, are time dependent and in principle reflects the state of the art of the engineering palette of materials, technological possibilities for construction elements, computational and simulation methods and methods of production to embody the chosen product concept, which are at the engineers disposal. Here the possibilities of a 21st century engineer are of course much greater than that of a 15th century engineer like Leonardo.

2.4 Production, marketing and sales – the return and profits of investments

Today in the period of information technology the marketing of new products are made long before the product is available in the market place illustrating how certain design steps also take place almost simultaneously. When the product meets the market we reach the moment of truth whether our predictions will hold and the product will be successful or not. Although Leonardo had concepts for methods of "mass" production and made some preliminary calculations on possible gains (Vezzosi, p.78) there is no evidence that he made any of those ideas come true in physical products. Leonardo was certainly not an entrepreneur.

3. LEONARDO'S METHODS AND APPROACH TO PROBLEM SOLVING

During a lifetime people change their point of view, which is a normal process and perhaps more so for an open-minded personality like Leonardo. So, of course, there may be no guarantee that Leonardo's approach to problem solving was the same during his lifetime. Nevertheless extensive research by e.g. Pedretti, Veltman or Gelb have made it obvious that Leonardo used conscious methods when he was solving problems or gaining knowledge.

Gelb has tried to summarize Leonardo's way of working in "The Seven Da Vincian Principles:

1. Curiosità – An insatiably curious approach to life and an unrelenting quest for continuous learning.
2. Dimostrazione – A commitment to test knowledge through experience, persistence, and a willingness to learn from mistakes.
3. Sensazione – The continual refinement of the senses, especially sight, as means to enliven experience.
4. Sfumato (Literally "Going up in smoke") – A willingness to embrace ambiguity, paradox and uncertainty.
5. Arte/Scienza – The development of the balance between science art, logic and imagination. "Whole-brain" thinking.
6. Corporalita – The cultivation of grace, ambidexterity, fitness and poise.
7. Connessione – A recognition of and appreciation for the interconnectedness of all things and phenomena. Systems thinking" (Gelb, p.9).

These principles may give us a sense of Leonardo's approach in his strive for an all embracing theory for the micro- and macrocosm of the world.

Pedretti discusses Leonardo's methods in a more scientific way. "Every aspect of Leonardo's technology, from the first to the last machine designs, can be related in some way to the technology of

his time … A study of the context to which a design belongs … reveals the techniques devised by Leonardo to improve existing devices" (Pedretti, p.76). In modern terminology Leonardo was working with incremental product development, as is the general basis for most engineering companies, and not with revolutionary innovations, except perhaps for his work on flying machines! Pedretti emphasizes also Leonardo's scientific approach by connecting theory with experiments. Therefore he was eager to learn and apply theories of mathematics especially geometry in the form of *perspective*, algebra to reveal *proportions* and *mechanics* "… the cornerstones of the scientific basis of the study of art" and "it is impossible to understand philosophy without knowledge of mathematics" (Ibid. p.36). It is important to know that a philosophy in Leonardo's renaissance terminology included anatomy, zoology, botany, geology, meteorology and astronomy. Theory and practice had to work together "… Leonardo recurred to experimental verification and contributed to the renewal of science by establishing mathematical justification as criterion for rationality" (Ibid. p.34). Also "every one of Leonardo's technological concepts is inspired by the examples of nature. In each of them, man as a living machine, is recognized as the insuperable model of inventive genius which can only in part be simulated by a robot … Within this context the close relationship seen by Leonardo between anatomy and technology, which led him to apply the same principles of drawing to both, becomes strikingly evident" (Ibid. p.50).

The methods of Leonardo according to Pedretti could perhaps be summarized by the following functional statements:

1. Study previous (ancient, medieval or contemporary) attempts to solve the problem.
2. Test the solutions with the help of theory and experiments and try to improve them.
3. Learn from nature, find new theory to test and try to apply it to the problem.
4. Use illustrations and technological drawings as tools for gaining knowledge.
5. Use illustrations and technological drawings to explain your concepts.

Veltman verifies that Leonardo in his "studies were guided by a distinct method of listing variables systematically and playing with them experimentally" (Veltman, p.39). He studied other "sources and challenged them also" and "The great number of machines and instruments with which he dealt was a vital ingredient in making the universality of his claims possible and credible" (Ibid. p.40). He had also, by 1492 "developed an explicit method for presenting his ideas that was reminiscent of the form Euclid established for classical geometry: a proposition (i.e. a claim), followed by demonstrations (i.e. examples based on experiment or at least experience), frequently accompanied by illustrations to show different possibilities" (Ibid. p.6)

From *The notebooks of Leonardo da Vinci* selected and edited by Irma A. Richter it is concluded : "He proceeded step by step.

1) Experience of the world around us gained through the senses is taken as the starting point.

2) Reason and contemplation, which, though linked to the senses stands above and outside them, deduces external and general laws from transitory and particular experiences.

3) These general laws must be demonstrated in logical sequence like mathematical propositions, and finally

4) they must be tested and verified by experiments, and applied to the production of works of utility or of art according to the plan" (Richter, p.2).

Thus there are many similar evidences of the methods used by Leonardo in his pursuit of solving problems or gaining new knowledge.

4. SIMILARITIES AND DIFFERENCES

Comparing our methods with Leonardo's shows a striking similarity. This is also demonstrated in Table 1. What differs is more a matter of number of technological tools than the methods themselves. Leonardo's method of listing and altering variables is similar to our parametric analysis or SCAMPER. The steps are more elaborate today but the general procedure is the same. The choice of the best concept is documented in a more rational procedure today than what is known about Leonardo's way of choosing concepts. But we still have the same admiration of the ideal way nature solves problems. So what can we can learn from Leonardo and the knowledge of his life and background? This will be discussed in the following paragraphs. An idea is that we should look at external facts from Leonardo's life – his environment, his behavior, his method of working – and try to imagine which of those *external causes* that could have made him so proliferate in generating (new)

engineering concepts. Then we should try to incorporate those *external causes* into our ideal model of product development methods.

5. DISCUSSION AND CONCLUSIONS

We will now discuss the process of product development from three relevant perspectives 1) ideal methods, 2) sources of ingenuity and 3) tools of knowledge respectively. The results of this discussion will help us make some tentative conclusions on preferable tools, methods and creative environments for modern product designers (§5.4).

Inspired by Leonardo we will also discus methods for a renaissance engineer of tomorrow (§5.5), methods on how to improve engineering programs curricula (§5.6) and methods on how to improve students interest in engineering courses (§5.7).

5.1 Ideas on ideal methods

The simplest solution is the best and most beautiful. That has been the spoken and unspoken guideline for scientists in finding solutions to problems from the ancient Greeks, over Leonardo's search for a mechanical explanation to the micro- and macrocosm of life and Einstein's quest for a unified field theory to scientists of today. Perhaps it is inherent in our construction as human beings an inability to handle too complex problems, we can only see simple solutions! Every conditions of constraints limits the possibility of solutions, so looking at problems from various points of view and with minimized conditions of constraints open up the space of possible solutions. This probably means that there are no one ideal method for product design but only *ideal methods as a mixture of* whatever *design tools* proven to be successful under some circumstances. The *multiplicity* seems to be the key word for product design methods. A conclusion would be that we should integrate Leonardo's tools into our box of useful design tools!

5.2 Ideas of sources of ingenuity

If we accept the principle of cause and effect (as a condition of constraint!) and let effect means creating ideas it is obvious that one way of improving the ability to come up with ingenious ideas is to pick up a lot of causes – impressions, ideas, circumstances, experiences, experiments, knowledge, competence, problems, solutions etc! Another conclusion would be that different causes probably give rise to different effects, so collecting different causes would create different ideas. The unique individual human being is the agent who has to collect those "causes" and produce those "effects" and therefore curiosity and a strive to learn new things can be a significant characteristic of a creative or ingenious person. Of course, the agent or "operator" which processes the "input of causes" into possible "outputs of effects", is a determining factor why certain people come up with ingenious ideas whereas others just produces "ordinary" ones. It seems that Leonardo was gifted with both curiosity and an extraordinary "idea generator". A conclusion would be that we should integrate Leonardo's methods into our box of useful design tools! In particular we must appreciate the power of sfumato!

5.3 Tools of knowledge

The *tools of knowledge* (what a wonderful phrase used by Pedretti) which gave Leonardo the prerequisites for his multidisciplinary attitude to life was the rich renaissance environment of different aspects of life represented by the cultures of Florence (F) and Milan (M) respectively. Art (F) and science (M), the civic stature of man (F) and the pragmatic technological solutions of problems (M) (Pedretti p.30). This was the interdisciplinary culture Leonardo was exposed to! In more straightforward terms the tools of knowledge must be whatever "tools" which help you to grasp new knowledge! Whatever tools that inspires your senses to create or accept new symbols (words, pictures etc.), new "languages" and to see new patterns and rules that will orient you in life, make your life

richer, make you happier, more satisfied or eager to learn more! The concept of tools of knowledge give us the hint to *foster a multidisciplinary environment*, where students can meet different pedagogical methods and rich possibilities to use all of their senses in their strive for new knowledge. Here new knowledge, of course, means new knowledge to an individual person, which on occasions (in "research") means new knowledge to mankind.

5.4 Conclusions on product development methods

Addressing the introductory question of "hidden methods of creativity" maybe they consist of a mixture of Leonardo's pronounced multidisciplinary "renaissance" field of interest, his focus to study and learn from man-made worlds (Veltman, p.9), to study, illustrate and learn from details of solutions, his interest in finding guiding principles for elements of machines (Ibid. p.18), and above all his vision of and quest for the methods of *nature* of solving problems "…because in *her* inventions nothing is lacking and nothing is superfluous." (Pedretti, p. 52).

However we must conclude that a *multiplicity of available tools* should be at the product designers disposal. The selection of tools is up to the designer and the design team and the creative "renaissance" *environment* should consist of *a mixture of art and science with an abundance of technological solutions at the designers disposal*!

5.5 Methods for a renaissance engineer of tomorrow

What do we mean by the idea of a *renaissance engineer of tomorrow*? IF it means a kind of *uomo universale* open-minded to every aspect of human life who can find innovative technical solutions to human problems, which are in resonance (!) with a good nature friendly way of living, a kind of modern Leonardo, THEN we can learn from Leonardo's approach to life as they are conceived by Gelb in his Seven Da Vincian Principles. Of course, there are no short cuts to that ideal. Instead it means hard work and "well-filled days" with a curious mind who always finds omniam mirare etiam tritissima. But the renaissance engineer of tomorrow should certainly be aware of deadlines, and know when "enough is enough". He or she should not be like Leonardo in every aspect! At the end of his life Leonardo wrote in his notebooks "Tell me, if anything at all has been done" (Williams, p.137). Leonardo's strive for the perfect made him uncertain of what he had achieved – he who wrote in his notebooks "Shun those studies in which the work that results dies with the worker" (Richter, p.274) – and hindered him to finish many of his commissions or projects.

5.6 Ideas from Leonardo on how to improve engineering programs curricula

During the course of life Leonardo's curiosity led him to shape his own university. How did it look like? His childhood gave him opportunities to explore the nature in the surroundings of Vinci. And already as an apprentice at his master Andrea del Verrocchio's workshop in Florence he met a mixture of artistic and engineering challenges. Although the whole life of Leonardo was a blend of "art and science" it is tempting to stress that in "his own university program":

a) he started with subjects that stimulated creativeness and ingenuity,

b) these subjects were "hands on",

c) later on he himself selected the order and what subjects he studied,

d) every working day was a mixture of artistic and scientific efforts according to White (White, p.287),

e) he designed costumes and stage sets for the theatre (which also stimulated his creativity in a more playful way) and finally (but most important as a driving force)

f) he had a vision for rules for the ideal solutions, e.g. the perfect face or body, in fact the rules of nature which forced him to acquire scientific tools from mathematics (geometry, algebra) and physics (mechanics).

In Williams book on the life of Leonardo the chapters in consecutive order are titled in the following way: 1) apprentice, 2) artist, 3) engineer, 4) inventor, 5) scientist and finally 6) uomo universale. That order could be a hint for a model for an engineering curriculum!

Do not kill creativity by overwhelming "scientific grammar" ("this is the state of the art of centuries of human efforts"!) in the first place. Start with hands on activities, sketches, over all pictures (crude models) and fill in with details at a pace the students (at the center) demands! For Leonardo the sight was the most important sense so he studied the shapes of things starting with the details and didn't continue to the next shape before he had memorized it and exercised on it long enough (Bramly, p.255). So studies of shapes of things will probably stimulate our most important sense and should probably be a regular part in engineering programs curricula. Why not try to imitate the natural learning by doing we as children learn our native languages! Curiosity – the seed for learning – is but a native characteristic of man to create the survival of the fittest, isn't it! Ideally the students should have a freedom to choose courses and subjects at their on will, although guided in the design of the curriculum by the experiences of the scholars. We should also make the working day of our students a mixture of different activities to use and stimulate all of their senses. Diverse subjects should be studied consciously guided by a vision that we can learn the working principles of nature and man and acquire knowledge to build a catalogue of construction elements and designing principles. This knowledge will help us as engineers in the design of useful tools, machines or products for the benefit of man and in conformity with nature.

Why not make *the theatre stage* a model for an ideal base camp (or playground) for engineering study? "On stage" we can consciously combine the imaginable with the unattainable, the realistic product with the dreams to really challenge and sow seeds for future worlds. The theatre stage is both a working place for building sceneries (models of reality) and a place for showing artistic performances. It is a natural habitat for the merger of art and science! Isn't that an inspiring implication of Leonardo's method of learning?

5.7 Ideas from Leonardo on how to improve students interest in engineering courses

In his "own courses" Leonardo had an insatiable curiosity. There he was at the center and the "courses" changed the content and responded to the needs of Leonardo. There is an interesting analogy with a modern activity that can be addictive to students, namely computer games! The computer games can catch the students interest (by a challenge or a story, moving pictures and appropriate sounds), let the student be at the center, make the student's activity unique and respond to that unique play of the student! Computer games are thus like "Leonardo courses". To travesty the introductory Latin phrase of this article we as teachers should make every course (and course plan) "worthy of its students", so that our students could honestly say: "Every course I had in my engineering program was worthy of a thesis!". And Leonardo from his heaven would smile and say: Dear student! "In rivers, the water that you touch is the last of what has passed and the first which comes: so with time present. Life if well spent is long." (Richter, p.274).

References:

Baxter, M. 1999. *Product design – Practical methods for the systematic development of new products*, Stanley Thornes Ltd, Cheltenham, U.K.
Bramly, S. 1994. *Leonardo – The artist and the man*, Penguin Books, London, England.
Gelb, M. J. 1998. *How to think like Leonardo da Vinci*, Dell Publishing, New York, USA.
Olsson, E. 1997. *Industriell produktutveckling*, IDP, Mälardalen University, Eskilstuna, Sweden.
Pedretti, C. 1999. *Leonardo – The machines*, Giunti Gruppo Editoriale, Florence, Italy.
Pugh, S. 1990. *Total Design – Integrated Methods for successful Product Engineering*, Addison Wesley. ISBN 0-201-41639-5.
Richter, I.A. (Ed.) 1998. *The notebooks of Leonardo da Vinci*, Oxford Univ. Press, U.K.
Veltman, K.H. 1998. *Leonardo's method*, http://sumscorp.com/books/leometh.htm
Vezzosi, A. 1997. *Leonardo Da Vinci – konstens och vetenskapens mästare*, Berghs Förlag AB, Stockholm, Sweden.
White, M. 1999. *Leonardo – The first scientist*, Time Warner, U.K.
Williams, J. 1966. *Leonardo da Vinci*, Allhems förlag, Malmö, Sweden.

Other sources used but not cited:

Ambrose, B. 2000. *Leonardo's Machines*, Tarquin Publications, Norfolk, England.
Brown, D.A. 1998. *Leonardo da Vinci – Origins of a genius*, Yale Univ. Press, New Haven & London.
Buchholz, E. L. 2000. *Leonardo da Vinci – Liv och verk*, Könemann, Hong Kong, China.
Cianchi, M. *Leonardo da Vinci's machines*, Becocci Editore, Kina Italia S.p.A., Milan, Italy. ISBN 88-8200-003-6.
Clark, K. 1993. *Leonardo da Vinci*, Penguin Books, London, England.

Product development methods

Interpreted Leonardo method

Main steps	Tools			
1. Problem / Customer need	Assigment from employer			
	Leonardo sees a problem			
2. What is the problem?	Illustrate the problem	Solved by others?	Ancient solutions?	Technological drawings
			Medival solutions?	Technological drawings
			Contemporary solutions?	Technological drawings
		Similar problems in nature?	Study solutions made by nature	Sketch concepts
	Problem analysis			
3. Concept generation	Improve previous solutions	Technological drawings		
	List and alter variables	Sketch concepts		
		Test ideas experimentally		
4. Concept selection	Nature exposes ideal solutions			
	Test technical feasibility			
	Artistic feeling	The chosen concept should express the idea of the solution		
	Intuition			

Modern engineering education methods IDP / MdH

1. Problem / Customer need	Assignment			
	"Gap" in the market			
	QFD (Quality Function Deployment)			
	Crude product specification			
2. Product functional analysis	Problem analysis			
	Main product functions?	Part functions?		
	Supporting functions?			
3. Concept generation	Idea generation	Product function analysis		
		Brainwriting		
		Brainstorming		
		SCAMPER		
		Parametric analysis		
		de Bono 6 hats		
		Other creativity methods		
		Sketch ideas		
	Combine ideas			
	Task analysis			
	Styling principles			
	Life cycle analysis aspects			
	Sketch concepts	Design aspects important		
4. Concept selection	Appropriate concept?	Task analysis		
		Styling principles		
	Technical content?	Test technical feasibility		
		Life cycle analysis aspects		
	Product specification demands?			
	Evaluation matrix (Pugh)			
Embodiment design	CAD-models			
	DFMA (Design for Manufacture and Assembly)			
	Modular design aspects			
	Product structure			
	Materials selection			
	Manufacturing methods			
	Suppliers			
	Prototypes/ simulations / tests			
	FMEA (Failure Mode Effect Analysis)			
Detail design	Detailed product specification			
Zero order series production				
Field tests				
Series production				
Follow up program				
Project closure				

Table 1