

A Heuristic Approach to Innovative Problem Solving

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ABSTRACT

A methodic approach to innovative problem solving is suggested. First, Bayesian techniques are analyzed for quantifying, monitoring and predicting the process. The symmetry of Bayes' theorem implicates that the chances of success offrail ideas with small base rates can be boosted by highly accurate tests built on solid scientific ground. Second, a hypothesis is presented in which five methodic elements – connection, selection, transformation, balance and finish - are deemed to be necessary and sufficient to explain innovative solutions to complex problems. The hypothesis is supported by the analysis of disruptive innovations in several fields, and by emulation of a data base including 40,000 inventions. The reported findings may become useful in the further methodic development of innovative problem solving, especially in the risky and lengthy preconceptual phases.

Keywords: Innovative problem solving, heuristic reasoning, Bayes' theorem, methodic elements, innovation strategies.

I. INTRODUCTION

Disruptive innovations are invariably based on solutions to many-faceted problems, the roots of which are commonly traced to several scientific disciplines [1-6]. The importance of unconventional and cross-disciplinary thinking for innovative problem solving has been underlined by entrepreneurs, analysts and psychologists [7-9].

In this paper, a methodic approach to innovative problem solving is suggested. It is leaning heavily on the pioneering work by Pólya [10], highlighting the paradoxical nature of the mental processes involved. "The inventor's paradox" (ibid. p. 121-122) is classical: "The more ambitious plan may have more chances of success." The benefit of "thinking backwards" (ibid., p. 225-232) in addition to more conventional forward-striving was pointed out. Pólya also reintroduced heuristic reasoning (ibid. p. 113-114) from the old Greek; the use of rules of thumb or educated guesses to approach a problem, however, without de-emphasizing the importance of rigorous proof or scrutinizing validation of the final solution.

The methodic approach in this paper includes one probabilistic part enabling the stepwise progress towards a solution to be quantified and monitored. The second part is a hypothesis that five methodic elements are necessary and sufficient for solving even extremely complex problems. The methodic elements and their underlying analysis are shortly described with reference to literature and elementary facts. The results section includes observations concerning both the probabilistic and the hypothetical parts. Finally, the validity and the usefulness of the findings are discussed.

II. METHODS

The process of innovative problem solving may be viewed as a chain of events, as schematically depicted in Fig. 1. The starting point could coincide with the sudden revelation of an emerging barrier, or the problem may build up gradually through analytic or creative insight. This point is denoted as 'problem recognition'. It is commonly followed by further analysis and creative thinking in order to arrive at some idea on how to proceed. A step of major importance is to develop a working principle that theoretically could carry the idea all the way to a solution.

A working principle should be realistic but may still be too immature to be tested against reality. A concept, on the other hand, should be a prototype of the final solution, although it may still have imperfections remaining to be resolved. The concept will be subjected to all sorts of tests, some of which will pass, whereas others may fail. Multiple redefining iterations on all previous levels may have to be carried out before an acceptable solution is reached.

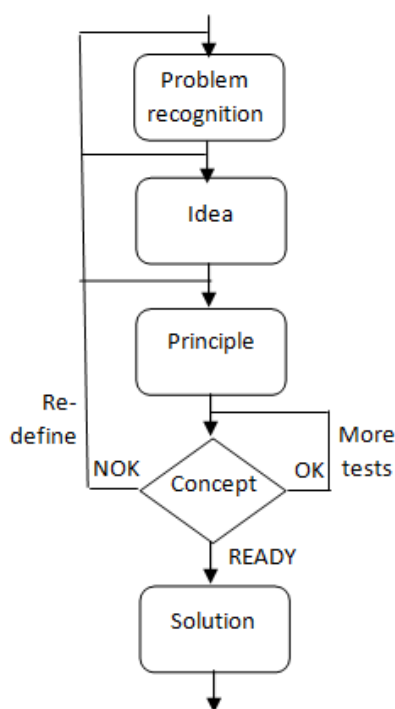


Figure 1. Flowgraph of innovative problem solving.

Innovative problem solving is a high-risk operation, and probabilistic methods should therefore be potentially useful. A methodic approach is believed to minimize risks and to improve the process efficiency. The classical Bayes' theorem [11] offers a unique possibility to quantify and monitor progress. It expresses the conditional probability $P(A|B)$ of an event A to be true when another event B is true. $P(A|B)$ is uniquely defined by the individual probabilities $P(A)$, $P(B)$ and the reverse conditional probability $P(B|A)$:

$$P(A|B) = \frac{P(B|A) \cdot P(A)}{P(B)} \quad \dots (1)$$

If $P(A)$ represents the base rate, or initial probability of reaching the solution to a problem, and $P(B)$ is the probability of a test result to be true, then $P(A|B)$ will express the expected progress due to the test.

In addition to the work breakdown structure outlined in Fig. 1, the task of problem solving is divided into five methodic elements, the usefulness of which will depend on the character of the problem, and by the position within the process according to Fig. 1. A short description of each element is given below.

Connection of hitherto unconnected aspects related to the problem is the first element. It has the power of resolving inconsistencies by introducing new perspectives to the problem. According to psychologists, human creativity is related to

the ability of the brain to establish connections between remote memory areas [8, 12]. To problem solvers, the 'aha' or 'eureka' experience may be synonymous with an inventive step, and this notion is even recognized by legislators. For an invention to be patentable, it should not 'be obvious to a person skilled in the art' [13]. The discovery of unexpected connections seems to be at least partly subconscious [9, pp. 24-25] but is commonly combined with analytical reasoning [9, pp. 66-67].

Selection is in many ways complimentary to connection. It brings an issue to its head, and it sets a limit to the seemingly endless connections and associations. It is useful for finding a critical item among a large amount of data, to divide a complex problem into manageable subtasks, and to focus on the most important ones. Whereas connection is related to the mathematical operations of addition and integration, selection is linked to subtraction and differentiation.

Transformation is a mapping operation from one domain into another. In applied mathematics, it may be exemplified by the Fourier and Laplace transforms. The human brain is able to transform physical objects into mental images via sensory receptors, and further processed at higher cognitive levels. Size, position, shape, character, color, time/frequency, are a few examples of transformable domains. Transformation may be an iterative, multistage process, and it is scalable from local to global dimensions, from neural to psychological behavior, from technological to social, and even political domains.

Balance has to be employed when dealing with inseparable opposites (black/white, plus/minus, male/female, etc.). When circumstances are changing with time, active balancing using feedback control needs to be employed. Ultimately, the multitude of aspects in a complex problem situation requires a balanced view.

Finish is a unique element in which a concept is converted into a complete solution verified and validated by testing and refining until all the prescribed requirements of the solution are fulfilled.

The hypothesis put forward in the introduction that the five elements are necessary and sufficient for innovative problem solving has been subjected to two separate investigations, both being examples of 'reverse engineering'. The first investigation seeks to examine timing properties and to find heuristic explanations in view of the methodic elements to some disruptive innovations in science, technology and politics, more specifically the general theory of relativity [14, 15], the disclosure of the DNA molecular structure [16], the abolition of apartheid [17], the invention of the world wide web [18], and the iPhone innovation [19].

The second investigation is based on data obtained from Altshuller et al [20], commonly referred to as the TRIZ method (Russian acronym, freely translated as the *theory of inventive problem solving*). The 40 solution principles of Altshuller's contradiction matrix assembled from a data base of 40 000 inventions (ibid. p. 261-276) may be assigned and reduced to the five methodic elements, allowing the incidence and links between them to be quantified.

III. RESULTS

An alternative expression of Bayes' theorem (eq. (1)) following directly from basic probability definitions is this equation:

$$P(A|B) = \frac{P(B|A) \cdot P(A)}{P(B|A) \cdot P(A) + P(B|\bar{A}) \cdot P(\bar{A})} \quad \dots (2)$$

By \bar{A} is meant the complimentary of A. Equation (2) was used to generate the graph shown in Fig. 2, in which $P(A|B)$ is plotted against the base rate $P(A)$ with three parameter settings of $\Delta = P(B|A) - P(A)$.

The S shape of the curves is more pronounced at small values of Δ , and illustrates the non-linearity appearing at small and big base rates. When $P(A) \rightarrow 0$ the slope of the curves increases with increasing Δ .

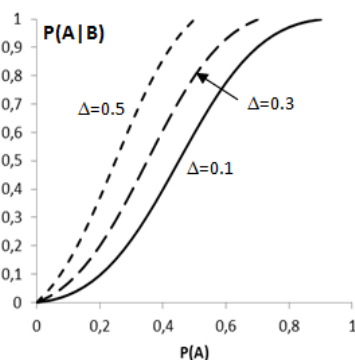


Figure 2. The three S-shaped curves directly follow from Bayes' theorem assuming a constant difference $\Delta = P(B|A) - P(A)$.

It is observed that the curves are symmetric to rotation 180°. This is a direct consequence of the symmetric nature of Bayes' theorem with respect to substitution between the arguments A, B, and their complementaries. A further consequence is this: to achieve a conditional probability $P(A|B) > 50\%$, the base rate $P(A)$ must be matched with a test probability $P(B|A) > (1 - P(A))$. The slightly modified version of eq. (2)

$$P(A|B) = \frac{1}{1 + \frac{P(B|\bar{A}) - P(\bar{A})}{P(B|A) - P(A)}} \quad \dots (3)$$

illustrates a related observation: When $P(B|\bar{A}) \ll P(\bar{A})$, then $P(A|B)$ will approach unity asymptotically. A numerical example: If the base rate $P(A) = 1\%$, $P(\bar{A}) = 99\%$, $P(B|A) = 99.99\%$ and $P(B|\bar{A}) = 0.01\%$, then $P(A|B) = 99.02\%$.

The risk exposure of the early phases of innovative problem solving is highlighted by the approximate durations of the preconceptual and finishing phases of the investigated disruptive innovations [14-19] depicted in Fig. 3. The total duration ranged from 8 to 33 years, and the average of the preconceptual phases were 89% of the total duration.

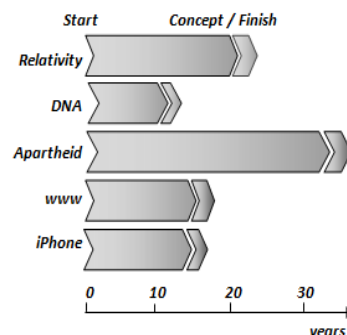


Figure 3. The approximate duration of the preconceptual and finishing phases of the investigated innovations.

The methodic elements described in the method section were combined to provide heuristic explanations of the disruptive innovations. Some examples are given below.

In Einstein's general theory of relativity, the entities of time and space were connected into a non-Euclidean, four-dimensional space-time, resolving inconsistencies related to Newtonian gravity and inertia. The consistency of the theory was secured by the mathematical transformations describing the detailed interdependence of space, time, matter, and energy.

The disclosure of the DNA molecular structure was enabled by a transformation process from the observed X-ray diffraction pattern generated by a DNA specimen into the double helix molecular structure in which the genetic code is stored in a replicable fashion.

In his struggle for human rights and against apartheid, Nelson Mandela successfully adopted a strategy of active balancing, ranging from militant action to reach awareness, via imprisoned passive resistance to gain acceptance, and finally, reconciliation to reach the stage of demand.

For the world wide web invented by Tim Berners-Lee, a surprisingly small number of items –

the universal resource identifier, the hypertext transfer protocol, and the hypertext markup language - were selected, interconnected and transformed into a unified concept which revolutionized the communication and management of digitized information.

The iPhone innovation included several interconnected items, the multi-touch screen and related software in particular, for the disruptive transformation of the cell phone into an attractive multipurpose tool and toy, fitting into everyone's pocket.

Table 1 is a summary of the extent to which the methodic elements explainsome exceptional problem-solving achievements.

Table 1. The major (X)or minor (x) extent to which exceptional achievements can be explained by the methodic elements connection (C), selection (S), transformation (T), balance (B).

<i>Exceptional achievement</i>	<i>C</i>	<i>S</i>	<i>T</i>	<i>B</i>	<i>F</i>
General theory of relativity	X	x	X	x	x
DNA molecular structure	x	x	X	x	x
Abolition of apartheid	X	x	x	X	X
World Wide Web innovation	X	X	X	x	x
The iPhone innovation	X	x	X	x	X

The small 'x's in Table 1 indicate that these methodic elements were actually influential, but to a minor degree. For example, in the Einstein case, there was a selection towards macrocosmic phenomena rather microcosmic, a balance between collegial involvement or not, and adramatic finish. But the influence of these elements on the total outcome was not decisive. Correspondingly, it is possible to trace some aspects of all methodic elements also in the other cases of the investigation.

Fig. 4schematically illustrates how certain elements are associated with different phases of the problem-solving process.

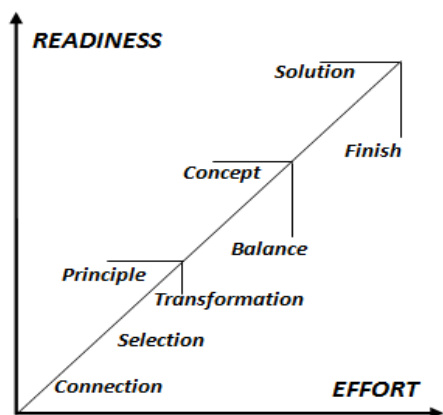


Figure 4. Schematic relation between solution readiness and effort positioning the major usefulness of the methodic elements.

Connection and selection are primarily used in the pre-principle phase to resolve inconsistencies. Transformation is a crucial element for refining a principle into a viable concept. The balancing element is useful for bridging quantifiable gaps, and the finishing element is required to close all remaining issues until a complete solution exists.

The TRIZ method [20] is based on the analysis of 40,000 inventions using a 39 x 39 matrix of improved characteristics to identify the action of 40 solution principles. In the present study, each one of Altshuller's 40 principles has been attributed to one of the five methodic elements according to Table 2.

Table 2. Assignment of the TRIZ solution principles [20] to the methodic elements connection (C), selection (S), transformation (T), balance (B) and finish (F).

	TRIZ principles	C	S	T	B	F
1	Segmentation		X			
2	Extraction		X			
3	Local Quality		X			
4	Asymmetry		X			
5	Consolidation	X				
6	Universality		X			
7	Nesting (Marioshka)	X				
8	Counterweight					X
9	Prior counteraction			X		
10	Prior action	X				
11	Cushion in advance	X				
12	Equipotentiality				X	
13	Do it in reverse			X		
14	Spheroidality			X		
15	Dynamicity			X		
16	Partial/excessive action				X	
17	Translating, dimension			X		
18	Mechanical vibration			X		
19	Periodic action			X		
20	Continuity of action			X		
21	Rushing through					
22	Convert harm/benefit			X		
23	Feedback				X	
24	Mediator	X				
25	Self service	X				
26	Copying					X
27	Dispose			X		
28	Replacement			X		
29	Pneumatic/hydraulic			X		
30	Flex films, membranes			X		
31	Porous materials					X
32	Changing color			X		
33	Homogeneity					X
34	Reject, regenerate			X		
35	Transformation			X		
36	Phase transition			X		
37	Thermal expansion			X		
38	Accelerated oxidation					X
39	Inert environment			X		
40	Composite materials			X		

The result from the TRIZ analysis is summarized in Fig. 4, showing the relative incidence of each of the methodic elements, and their cross-links based on data obtained from Altshuller et al [20]. Both incidence and cross-links are dominated by the transformation and finishing elements, whereas the role of the balancing element is considerably weaker.

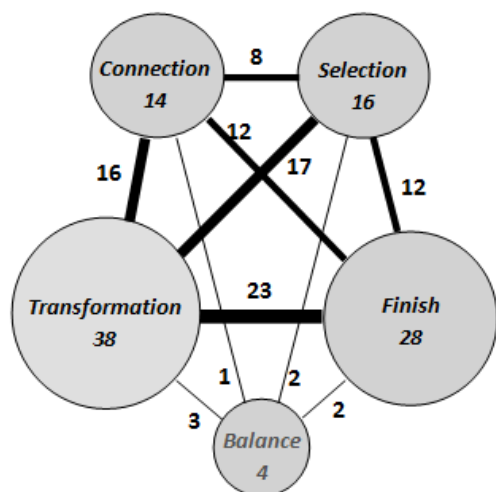


Figure 5. Relations between the five methodic elements with respect to incidence (numbers within the circles expressed as % of total) and cross-links (numbers at the respective intersecting lines, also expressed as % of total). Original data obtained from Altshuller et al [15].

IV. DISCUSSION

The observations concerning Bayes' theorem provide a strong indication for the usefulness of Bayesian techniques in quantifying, monitoring and predicting the progress of innovative problem solving processes. The symmetric nature of Bayes' theorem, equation (3), and the numerical example demonstrate that a test resting on solid scientific ground, and therefore having an extremely small rate of false positives, can indeed override the influence of the base rate. This fact is of importance in all phases of innovative problem solving, although it may sound contradictory to the 'base rate fallacy' taught by psychologists; the human tendency to trust anecdotes more than statistics [8, p. 146-155].

The hypothesis put forward in the introduction is supported by the analysis of some disruptive innovations in various fields, indicating that heuristic explanations based on the five methodic elements can be given, even to the solutions of such complex problems.

As indicated in Fig. 4, the connective element is primarily useful in the early phases of the problem-solving process, and in the presence of barriers which are difficult to quantify. A selection process may divide a highly complex problem into separate and manageable parts, enabling the most

critical ones to be isolated from irrelevant disturbances. A creative transformation may, like an unexpected connection, resolve barriers of inconsistency. The balancing element represents an "emergency exit" to manage inseparable and opposing units. During the finishing process, all aspects of the project need to be tied together into a unity. In the final stage, the perspective should be turned inside out, starting to develop the consequences of an existing solution.

From the emulation of TRIZ data [20] summarized in Fig. 5, it is concluded that the transformation and finishing elements are dominating within the data base of mid-20th century inventions in the fields of mechanical and electrical engineering. This is consistent with expectations in view of the fact that most of the inventions in the data base were incremental, rather than disruptive.

The hypothesis brought forward in this paper will remain a hypothesis until more substantial evidence has been gathered. The findings may potentially become useful to innovative problem solvers, especially in the early stages of development. The importance of improved methodic development directed towards the preconceptual phases is underlined by Fig. 3, illustrating the dominance of these phases in the overall duration.

V. CONCLUSION

It is concluded that Bayesian techniques are useful for quantifying, monitoring and predicting innovative problem solving processes. It follows from Bayes' theorem that a test with extremely small rate of false positives may override a small base rate. The hypothesis that five methodic elements - connection, selection, transformation, balance and finish - are necessary and sufficient may become useful in the further methodic development of innovative problem solving, especially its risky and lengthy preconceptual phases.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the inspiration from numerous colleagues and friends, in particular the valuable comments on the manuscript by Lasse Tenerz, Håkan Pettersson, and Henrik Rödjegård.

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