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Creative Heuristics

A Framework for Systematic Creative Problem Solving

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Abstract

Creativity in inventive problem solving usually takes place in the middle of the continuum of sheer chance and safe bet. Inventors normally use creative heuristics which provide them with promising search fields and directions for inventive problems. The paper at hand analyzes the existing frameworks of heuristic principles described in scientific literature about invention and insight, and proposes a framework of creative heuristics. Furthermore existing heuristics from invention and insight research are allocated to the principles in the framework. Thus, the proposed framework of creative heuristics can be used as a toolbox in creative or inventive problem solving and as a means to promote creativity in engineering education.

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Carsten Deckert

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1 Introduction

"I believe there are important general principles underlying invention,
and our understanding of these principles
can make us more appreciative of the built world around us."
(Weber 1992a, p. vii)

Nowadays creative problem solving is seen as one of the core skills of the 21st century e.g. by the Partnership for 21st Century Learning (P21 2015), a coalition founded by the U.S. Department of Education and leading U.S. companies. Creativity is also seen as a key success driver of companies contributing to an organization's growth and long-term survival (Mathisen & Einarsen 2004, p. 119, Oldham & Baer 2012, p. 387), and the majority of surveys by renowned consultancies propose a positive relationship between a company's innovations and its performance (see e.g. Arthur D. Little 2010, Jaruzelski, Staack, & Schwartz 2015, PwC 2013, Ringel, Taylor & Zablit 2015). Consequently the OECD (2013) sees creativity and innovation as important driving forces of economic development fostering competitiveness, productivity, and the creation of new jobs.

The main problem with creativity is that it is hard to ignite and even harder to manage. Even if a problem solver is well under way it is often unclear, if he gets a breakthrough idea and finds an adequate solution to his problem or not. So creativity seems to rely to a certain extent on sheer luck. On the other hand algorithmic approaches to problem solving run the risk of sticking with the tried and true and of not leaving the comfort zone of the problem solver. Thus, opportunities to improve existing products and services are likely missed.

In their study of inventors Perkins & Weber (1992, p. 320 ff.) find that in a continuum between sheer chance and safe bet, inventors tend to work in the middle – in the range of systematized chance, fair bet and good bet. This does not mean that inventors do not use chance occurrences along the way. In fact, inventors often see chance events as opportunities and incorporate them into their work when they occur. But it means that inventors use some kind of systematization in their search for a solution (Perkins 1996, p. 130 ff., Perkins 2000, p. 94 f.). So inventors do seem to make use of "important general principles" as the initial quote of Weber (1992a) suggests.

The question is, what these "important general principles underlying invention" (Weber 1992a, p. vii) are. There are several frameworks proposing inventive heuristics and paths to insight. Some come from the historical analysis of inventions, others from the accounts and observations of inventors and people solving insight problems. The aim of this paper is to develop an overall framework of creative heuristics fostering creative or inventive problem solving.

To achieve this aim the paper is structured as follows. In chapter 2 preliminary considerations about creativity are described. In particular the terms functional creativity and invention are defined, the problem space of tasks requiring creative problem solving is circumscribed and the human biases inhibiting creativity are analyzed. Along the way intermediate results about creative heuristics are recorded. In chapter 3 the term creative heuristic is defined based on the preliminary considerations. Furthermore different frameworks are analyzed and compared to determine their heuristic principles. From these principles a framework of heuristic principles is developed. In chapter 4 different heuristics from the literature are allocated to the principles in the framework, so that the framework becomes a toolbox for inventors and problem solvers. All the analyzed heuristics are collected in the appendix of the paper for further use. Finally in the conclusion the possible utilization and the limitations of the framework containing the creative heuristics are discussed.

2 Preliminary Considerations about Creativity

"The concept of creativity may trail clouds of glory
but it brings along also a host of controversial questions."
(Boden 1996a, p.1)

This chapter defines the main terms of functional creativity and invention. Furthermore related concepts such as technology and creativity are also described. Based on this, the problem space of creativity is analyzed and characteristics of problems requiring a creative solution are carved out. Finally the cognitive biases inhibiting creativity are determined starting from the overall "Bias against creativity". As an intermediate result some key findings about creative heuristics are obtained which will be used in chapter 3 to define what constitutes a creative heuristic.

2.1 Functional Creativity and Invention

According to Runco & Jaeger (2012, p. 92) the standard definition of creativity includes the two components originality and effectiveness. E.g. Sawyer (2012, p. 8) defines creativity as "the generation of a product that is judged to be novel and also to be appropriate, useful, or valuable by a suitably knowledgeable social group". A product should have novel attributes which are unusual, unexpected or even inconceivable and, thus, surprise us. But it should also solve a given problem and, thus, be in some form linked to the existing body of knowledge of a specific domain (Deckert 2015).

Cropley & Cropley (2005, 2008 & 2010) use the term "functional creativity" for industrial products such as engineered items or manufactured consumer goods. Functional creativity generates "novel products that serve some useful social purpose" (Cropley, Kaufman & Cropley 2011, p. 16). For functional creativity effectiveness is more important than originality. A novel product must fulfill its intended need. Otherwise it will not be considered creative, no matter how new and original it is (Cropley & Cropley 2008).

The product of functional creativity can be called an invention. The process of invention can be defined as the “generation of an economically efficient and reliably working means-end relation” (Zobel 2009, p. 1, own translation) based on familiar technical knowledge which is used in a new and often surprising way. The definition explicitly stresses the importance of effectiveness over originality. According to Weber (1992, p. 14) invention can be seen as “a subspecies of creativity, one in which the evaluative standard is primarily workability – as contrasted, say, with the aesthetic standards of arts”.

Invention is based on some form of technology. Technology can be defined as “the theoretical and practical knowledge, skills, and artifacts that can be used to develop products and services as well as their production and delivery systems” (Burgelman, Christensen & Wheelwright 2009, p. 2). So on the one hand technology is a special form of knowledge embodied in people and physical processes. On the other hand technology contains the artifacts which this special knowledge generates such as machines, tools and plants. In an industrial context technology can be either part of the sold product (product technology) or it can be used to manufacture products while not directly being part of the product (process technology) (Gerpott 2005, p. 26). When an inventive solution is commercialized it is usually called an innovation (Burgelman, Christensen & Wheelwright 2009, p. 2).

A more concise definition of technology is given by Hughes (2005, p.4) who defines technology as “craftsmen, mechanics, inventors, engineers, designers, and scientists using tools, machines, and knowledge to create and control a human-built world consisting of artifacts and systems associated mostly with the traditional fields of civil, mechanical, electrical, mining, materials, and chemical engineering” and from “newer fields of engineering, such as aeronautical, industrial, computer, and environmental engineering, as well as bioengineering”. This definition also includes the two components “technology as knowledge” and “technology as technical artifacts” and the creation of new products based on technology. But it also includes the aspect of controlling the technical artifacts and systems. Besides this definition is more precise as it limits the field to engineering and related activities, a field for which technical sociology in Germany typically uses the term “Realtechnik”[1] (Häußling 2014, p. 11).

From the historical study of technological development a basic understanding of the workings of invention can be gained. Basalla (2002) studies the variations and evolutionary paths of technical artifacts. In a similar way Petroski (1992) shows for everyday artifacts that “form follows failure” and that want rather than need drives the process of technological evolution. Kelly (2010) tries to discover technology’s trajectories such as complexity, diversity and specialization, and Arthur (2009) identifies some mechanisms of technological development along the technological lifecycle such as internal replacement and structural deepening. Furthermore this understanding of technological development can be used to infer and develop rules for invention. Altshuller (1984) analyzed about 40,000 patents to determine the physical effects used to solve technical problems as incorporated into his methodology TRIZ[2]. Norman (2013) analyzes how bad design ignores the needs of people and how good design can increase the usability of items. By contrast Weber (1996a, 1996b) analyzes simple hand tools and devices to uncover the “hidden intelligence of invention” and to generate creative heuristics of middle-range generality. While the main purpose of these heuristics is to facilitate invention, they can also often be fruitfully used in other domains, even in conceptual domains (Weber & Perkins 1989, p. 70).

Intermediate result:
Creative heuristics can be derived from functional creativity and invention, and are (at least partly) transferable to other realms.

[1] A possible translation could be “real life technology“.
[2] TRIZ is a Russian acronym for Theory of Inventive Problem Solving and denotes a method of systematic inventive problem solving developed by Genrikh Saulovich Altshuller (1926-1998). In English countries often the acronym TIPS is used (Orloff 2006, p. 3).

2.2 Problem Space of Creativity

According to Amabile (1996, p. 35) for a product to be judged as creative, the task should be “heuristic rather than algorithmic”. This means that the way to solve the problem is not entirely clear or straightforward. In some cases even the target to be achieved is not entirely evident. An example for an algorithmic task is baking a cake according to an existing recipe. A heuristic task would be to bake a new cake inventing a new recipe (Amabile 1996, p. 35 f.). So asking questions to find the right target or to transform the problem so that the target becomes more evident can be seen as a central part of creative problem solving (Sawyer 2013, p. 26 ff.).

Getzels & Csikszentmihalyi (1975, p. 101 ff.) distinguish presented problems from discovered problems. A presented problem has a known formulation and a routine solution approach. The discovered problem has no known formulation yet and lacks a routine solution approach. In between these two extremes there is a problem type which has a known formulation, but no routine solution approach yet. The solution of the presented problem requires memory and retrieval of the solution approach, and the solution of the intermediate problem requires reasoning and rationality, while the solution of the discovered problem demands imagination and creativity including a fair amount of problem finding.

The importance of problem finding is also highlighted in some creativity models. E.g. all versions of the Creative Problem Solving (CPS) models – one of the most renowned creativity approaches based on the work of Alex Osborn – include a phase at the beginning to analyze and understand der problem. The newer models even include phases such as “mess finding” or “constructing opportunities” to set the principal direction which precede the formulation of the problem to be solved and the generation of ideas (Geschka & Lantelme 2005, Isaksen & Treffinger 2004). In an overview of ten stage models of creativity by Sawyer (2012, p. 89) seven models contain an explicit phase to analyze and define the problem.

One category of problems which require creativity are so called insight problems. Insight problems are characterized by a fixation or impasse. This means that a person is misled by the given information of the problem and gets stuck. Insight problems often lead to a fixation on an inadequate solution approach blocking more adequate routes to a solution.

A famous example of an insight problem is the so called “candle problem” in which a person has to find a way to attach a candle to the wall. In this problem the fixation typically occurs as categorizing a box of thumbnails as just a container, and the insight is to overcome this categorization and use the box as a shelf to attach the candle to the wall (Sawyer 2012, p. 107 ff.). It is debated though if insight problems are the main problems of creative problem solving and if insight happens spontaneously by overcoming fixation (Runco 2014, p. 22 ff.).

Another problem often mentioned with regard to creative problem-solving, especially in the context of the method TRIZ[3], is the inventive problem. An inventive problem can be defined as “A problem containing a *contradiction* in the form of incompatible requirements and/or properties […] that cannot be solved by adequate methods and means” (Orloff 2017, p. 19). In this case the solution is not straightforward since the desired solution cannot be achieved with the existing means, but leads to a paradoxical requirement. Contradictions can occur in the form of general, standard or radical contradictions. A general contradiction can be described as “the general need to attain a certain property (or state) or remove an obstacle” (Orloff 2012, p. 24). Standard or technical contradictions emerge from two opposing requirements or conflicting targets, e.g. high speed and low gas consumption in a car. A radical or physical contradiction is a paradox where two contradictory properties must exist side by side in the same part, e.g. a surface must be both hard and soft at the same time. A solution can only be achieved by a new approach which overcomes the existing contradiction and eliminates the problem (Orloff 2012, p. 27 ff.).

Intermediate result:
A creative heuristic can help by overcoming fixation and/or resolving a contradiction.

For Boden (1996b, p. 79) creativity takes places in the conceptual space of a certain domain characterized by domain-specific constraints, e.g. mathematical notation, physical laws etc. Creative problem solving can take two routes. It can either exploit the full possibilities of the conceptual space or it can explore the limitations of the conceptual

[3] See footnote 2.

space. The latter case involves changing or eliminating some of the constraints. But it does not mean to get rid of all constraints because creativity always operates within the framework of some conceptual space and "To throw away all constraints would be to destroy the capacity of creative thinking" (Boden 1996, p. 79).

Perkins (1992, p. 241) distinguishes between two types of problem spaces: "Homing Spaces" and "Klondike Spaces". A Homing Space usually includes "a *target gradient* that leads to the target itself" making it possible to home in on possible solutions. Usually Homing Spaces are characterized by a more or less fixed number of possibilities (e.g. as defined by the rules of a game), few changes of possibilities through outside intervention and more or less fixed target or solution states (Perkins 2000, p. 72 ff.).

Borrowing from the search of gold in the Alaskan Klondike, Perkins (1992, p. 241) calls a problem space that requires creative problem solving a "Klondike Space". The main criterion of a Klondike Space is that is has "punctuate targets with sharply defined boundaries" (Perkins 1992, p. 241) making it hard to systematically improve the solution. Klondike spaces are also called fuzzy possibility spaces which have no clear rules for creating possibilities, frequent changes in the possibility space from the outside and no clear or evolving target states (Perkins 2000, p. 72 ff.). They are characterized by the following four problems:

- Rarity: "Payoff is sparsely distributed in a vast space of possibilities" (Perkins 1996, p. 122). This leads to a "wilderness of possibilities" and often to a long and wide search for possible solutions (Perkins 2000, p. 53).
- Isolation: "Regions of payoff often lie isolated or semi-isolated" (Perkins 1996, p. 122). This can result in a "narrow canyon of exploration" where no solution exists making a reframing of the situation necessary (Perkins 2000, p. 54).
- Oasis: "[…] regions of payoff or even promise are hard to leave" (Perkins 1996, p. 122). The problem solver is stuck in an "oasis of false promise" offering an easy compromise solution instead and stops pursuing his search for a better solution (Perkins 2000, p. 55).
- Plateau: "In many regions, directions towards greater promise are not clear" (Perkins 1996, p. 124). This is also called the "seemingly clueless plateau" by Perkins (2000, p. 54) since the Klondike Space often does not offer clues for a promising direction.

The distinction between Homing and Klondike Spaces is not a clear typology but rather a continuum of two opposite poles: Homing Spaces can incorporate parts of Klondike Spaces and vice versa. And Klondike Spaces can be treated like Homing Spaces by using creative heuristics to find promising target gradients (Perkins 1992, p. 243 ff.)

Intermediate result:
A creative heuristic transforms a Klondike Space – entirely or partly – into a Homing Space.

2.3 Biases Inhibiting Creativity

Examples of companies missing a business opportunity presented by functional creativity or an invention are legion. A reason for this can be ascribed to cultural lock-in due to shared mental models of the business model of a company. Usually these mental models help to navigate a business field in times of continuity, since they are based on the cumulated experience and knowledge of management. But in times of discontinuity these mental models can become a liability: They are not properly assessed and corrected for changing environments and, thus, tend to become inaccurate or are used in an improper way (Foster & Kaplan 2001, p. 63 ff.). Mental models tend to draw companies back to their original business model, even if obsolete, and hinder them to explore new products or new ways of doing business. Anthony (2012, p. 68) calls this phenomenon "the sucking sound of the core business".

Furthermore Mueller, Melwani & Goncalo (2011) found a bias against creativity leading people to reject creative ideas, even if they say that they desire a creative solution. This negative bias against creativity is caused by a need to reduce uncertainty making it hard for people to recognize a creative idea. Ray & Myers (2000) refer to a Voice of Judgement (VOJ) in people hindering them to accept their own or other people's creativity and describe it as follows: "This judgment condemns, criticizes, attaches blame, makes fun of, puts down, assigns guilt, passes sentence on, punishes, and buries anything that's the least bit unlike a mythical norm" (Ray & Myers 2000, p. 42). One way to circumvent the VOJ is to defer judgment in the process of idea generation. Additionally a preventive mind-set can motivate people to avoid a potential loss of a creative idea and stick with the tried and true (Kounios & Beeman 2013, p. 179 f.).

Another bias working against creativity is fixation. Fixation occurs when a person fixates on an inappropriate solution and cannot switch to a more appropriate solution. Insight problems are hard to solve particularly because they usually lead to a fixation on inappropriate approaches (Sawyer 2012, p. 110 f.), as described in chapter 2.2. Fixation can be caused by mechanized solution methods and functional fixedness. Mechanized solution methods are approaches which were successful in the past and are now used non-reflectively – also for problems where they do not adequately fit. Functional fixedness is the "inability to use familiar objects in an unfamiliar way" (Smith, Paradice & Smith 2000, p. 113) as e.g. in the classic "candle problem" described in chapter 2.2. A related concept to fixation is structured imagination or "the tendency not to deviate from what is already known in creative efforts" (Smith, Paradice & Smith 2000, p. 113) leading to similar results in creative endeavors from different individuals.

Some biases of intuitive thinking as described by Kahneman (2012) can possibly inhibit creativity, especially the endowment effect, the status quo bias, the confirmation bias and the availability bias. The endowment effect was discovered and named by Thaler (1980) and describes "the fact that people often demand more to give up an object than they would be willing to pay to acquire it" (Kahneman, Knetsch & Thaler 1991, p. 194). The endowment effect does not only work on material items but also on ideas making it hard for people to give up an unjustified belief (Ariely 2010, p. 177 f.). The status quo bias was first described by Samuelson & Zeckhauser (1988, p. 47) and can be described as a "bias toward sticking with the status quo". Endowment effect and status quo bias are both caused by the more fundamental bias of loss aversion (Kahneman 2012, p. 278 ff.). Both biases lead to mental inertia or the tendency to stick with old approaches and work against the acceptance of new ideas.

The confirmation bias can be described as "a generic concept that subsumes several more specific ideas that connote the inappropriate bolstering of hypotheses or beliefs whose truth is in question" and usually refers to an "unwitting selectivity in the acquisition and use of evidence" (Nickerson 1998, p. 175). It is a central bias with regard to knowledge acquisition and termed "the mother of misconceptions" by Dobelli (2014, p.

19).[4] The confirmation bias leads to amongst others preferential treatment and overweighting of positive evidence for existing beliefs, while contrary evidence is ignored or underweighted. Especially, given categorizations or taxonomies are often seen as describing the "real" structure of the world and treated as such – a phenomenon called reification (Nickerson 1998). This leads to old ideas being perceived as the way the world works, while the evidence for the success of new ideas is undervalued.

A related concept with regard to groups of people is the phenomenon called groupthink. The need for social conformity in members of a group can lead to pressure on dissenters to conform to the group's (sometimes unrealistic) opinion. The thinking involved has been called "groupthink". The term "groupthink" was first used by Janis (1973) and denotes a kind of thinking "when *concurrence-seeking* becomes so dominant in a cohesive group that it tends to override realistic appraisal of alternative courses of action" (Janis 1980, p.433). Groupthink became a popular practical concept leading to many empirical studies into its prerequisites and symptoms (Park 1990). Newer research shows that the reason behind groupthink is not so much social bonds of a group, but rather overconfidence and concerns for reputation of its members (Grant 2016, p. 185 f.). With regard to idea generation groupthink leads to pressure on dissenters, self-censorship and self-appointed mindguards to avoid deviations from the supposed group consensus and a shared illusion of unanimity within the group (Janis 1980, p. 438 ff.).

Under the availability bias a person judges instances based on cognitive ease. More specifically the probability of an event is estimated based on the ease of retrieval, search or imaginability of an instance (Tversky & Kahneman 1974, p. 1127). This obviously works against more creative solutions since original instances are harder to retrieve than standard instances, and the success of a totally new idea is harder to imagine than a previously successful but now obsolete idea.

[4] It is, however, debatable whether this title should go to the conformation bias or rather to the phenomenon of loss aversion. Loss aversion is seen as the cause of several biases such as the endowment effect and the status quo bias (Kahneman, Knetsch & Thaler 1991)

The endowment effect, the status quo bias, the confirmation bias and the availability bias all favor existing ideas, products or business models. In doing so, they tend to emphasize effectiveness over originality. It can be assumed that the biases of intuitive thinking are at least partly responsible for fixation and the general bias against creativity. As a summary of this chapter the following quote by Koestler (1967, p. 190) seems to be appropriate: “To acquire a new habit is easy, because one main function of the nervous system is to act as a habit-forming machine; to break out of a habit is an almost heroic feat of mind or character. The prerequisite of originality is the art of forgetting, at the proper moment, what we know.”

Intermediate result:
A creative heuristics should help to overcome one or several biases operating against creativity.

3 Framework of Heuristic Principles

"The first rule of discovery is to have brains and luck.
The second rule of discovery is to sit tight and wait till you get a bright idea."
George Polya (1988, p.172), mathematician

In this chapter the term "heuristics" is defined and the term "creative heuristics" is specified. Based on this definition different sets of heuristic principles for creative and inventive thinking from the literature of creative or inventive problem solving and insight generation are described and compared. From these heuristic principles of creative and inventive thinking a framework for creative heuristics is built.

3.1 Definition of Creative Heuristics

In the scientific literature there seem to be two kinds of definition of the term "heuristics" with somewhat differing meaning. One kind of definition is from the field of decision making and choice, the other from the field of problem solving and creativity. In both fields heuristics refer to some kind of rules of thumb.

In decision making these rules of thumb distill the most important information of a situation for the given choice and ignore the rest (Gigerenzer 2008, p. 18). In particular the heuristics "reduce the complex task of assessing probabilities and predicting values to simpler judgmental operations" (Tversky & Kahneman 1974, p. 1124). This often leads to useful and good enough solutions for complex problems, but at the same time also leads to biases and decision errors under certain circumstance (see chapter 2.3) (Kahneman & Klein 2009). In the field of decision making there is often a clear target or a rational choice to be favored and the discovered heuristics have a descriptive character.

In the field of problem solving a heuristic can be described straightforwardly as "a strategy or rule of thumb for generating ideas or for solving problems" (Weber 1996a, p. 83) and the study of heuristic as "the method and rules of discovery and invention" (Polya 1988, p. 112). More specifically Carlson & Gorman (1992, p. 48) define heuristics in the field of invention as “the strategies and tactics an inventor uses to generate and manipulate mental models and mechanical representations”. In this definition mental models are the ideas and concepts of the inventor, and mechanical representations are the physical devices from which the inventor can build his inventions.

The heuristics in problem solving can be derived from the study of inventors or from the study of the evolution of technologies and inventions. These studies do not aim at finding the real mental operations which guided inventors at the time of their invention. They rather try to uncover principles and rules leading to these solutions which might be used by future inventors to guide them in solving their problems (Weber 1992b, p. 218). So the main target is to find “*mental operations typically useful”* in the problem-solving process (Polya 1988, p. 129 f.). For this reason, heuristics in problem solving deal with open-ended problem situations in which the targets are not always clear and there is no obvious rational solutions, and they are prescriptive rather than descriptive.

The heuristic principles so found should be of medium generality, neither too specific to make them useless for other similar problems, nor too general as to possess only a weak power to create meaningful concepts and are not much more helpful than a random search (Weber 1992a, p. 84 ff., Weber & Perkins 1989, p. 50 f.). This generality ensures that heuristics provide “procedures which are independent of the subject-matter and apply to all sorts of problems” (Polya 1988, p. 133).

Apart from sufficient generality, heuristics in problem solving typically take into consideration the logical and psychological background as well as the unbiased experience of discoverers and inventors and pursue practical aims rather than scientific accuracy. Although heuristics in problem solving are prescriptive, they do not deliver a ready-made solution due to their broad generality, but rather particularly promising directions to search for a solution. As such they are not unfailing rules but rather guidelines for discoverers and inventors (Polya 1988, p. 172). “Heuristic reasoning is reasoning not regarded as final and strict but as provisional and plausible only, whose purpose is to discover the solution of the present problem” (Polya 1988, p. 113). This medium generality excludes all general tips on how to be creative and overcome mental blocks such as free association or asking probing questions (see e.g. von Oech 2008) since these tips do not provide a concrete direction for the search but simply rely on the inventor eventually hitting on an idea through enough more or less random trials and searches. It also excludes methods and approaches tied to one invention type or industry, if the transferability of these rules to other realms is not clear.

From the intermediate results in chapter 2 we can add that creative heuristics have the following additional characteristics. Even if creative heuristics are derived from the field of functional creativity and invention, their application might go beyond this field into other fields such as science or arts due to the middle range in generality. Creative heuristics can help overcome human biases working against creativity, especially functional fixation, and find promising directions for a solution search by transforming a Klondike Space – entirely or partly – into a Homing Space.

3.2 Heuristic Principles

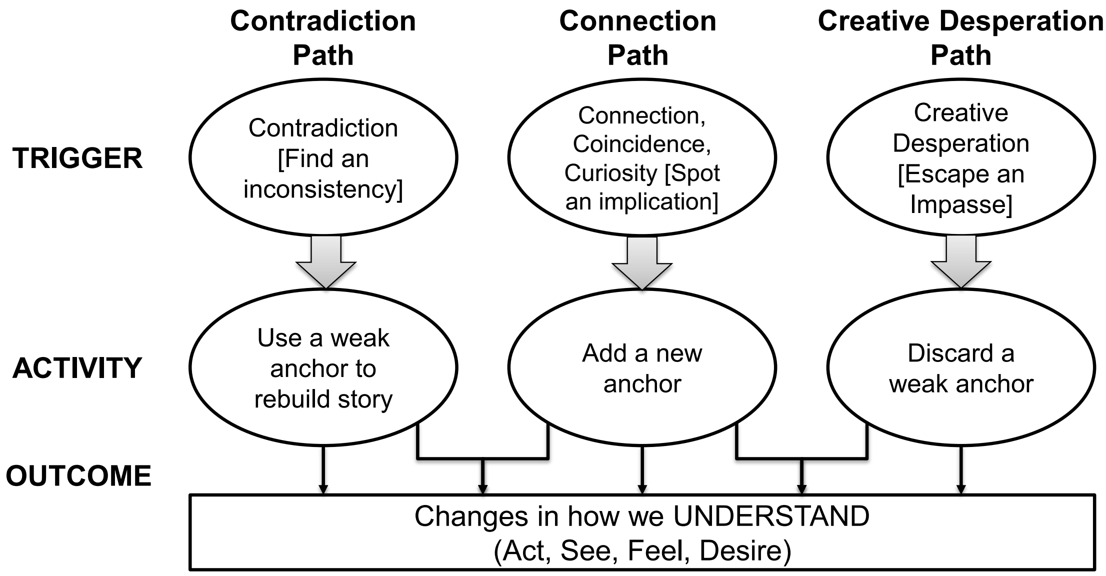
In the literature on creative or inventive problem solving and on insights there are several explanatory frameworks for heuristic principles supposed to facilitate creative or inventive thinking. One basic concept is Lateral Thinking by de Bono (1990). Lateral thinking is described as a deliberate and practical process related to insight, creativity and humor. The target of lateral thinking is to restructure insights, i.e. fixed mental patterns. The two basic principles of lateral thinking are the generation of alternatives and the challenging of assumptions.

De Bono (1999, p. 37 ff.) distinguishes lateral thinking from vertical thinking. Vertical thinking is a logical way of thinking using existing mental patterns and sequential reasoning based on relevant information to achieve one solution. By contrast, lateral thinking breaks up fixed mental patterns and uses several different ways of looking at a problem using also unusual or irrelevant information. Lateral and vertical thinking are not contradictory, but rather can be seen as complementary ways of thinking.

With regard to *insight problems* (see chapter 2.2) the two concepts of Sternberg & Davidson (1999) and Klein (2014) offer frameworks of underlying processes or paths for problem solving. Sternberg & Davidson (1999) developed a three-process theory of insight distinguishing three separate but related psychological processes. The goal of the three processes is to restructure the mental representation of a problem, more specifically an insight problem. The following processes are distinguished:

- Selective Encoding is "sifting relevant information from irrelevant information" (Sternberg & Davidson 1999, p. 65) and can be achieved when "a person finds in a stimulus […] one or more elements that previously have been nonobvious" (Davidson 2003, p. 158)
- Selective Combinations is "combining what originally might seem to be isolated pieces of information into a unified whole that may or may not resemble its parts" (Sternberg & Davidson 1999, p. 65). It includes the two aspects of which pieces should be combined and how they should be combined (Davidson 2003, p. 159).
- Selective Comparison is "relating newly acquired information to information acquired in the past" (Sternberg & Davidson 1999, p. 65) or discovering "a nonobvious connection between new information and prior knowledge" (Davidson 2003, p. 159).

Figure 1: Triple Path Model of Insight



Source: Klein 2014, p. 104

Klein (2014, 101 ff.) proposes a Triple Path Model for insights characterized by different triggers and activities (see fig. 1). The three paths to insight are as follows:

- The Contradiction Path is triggered by a detected inconsistency of the problem. The problem solver does not ignore or discard the inconsistency, but builds on it to revise the rest of his beliefs. This often includes discarding an earlier belief about the problem against conventional wisdom.
- On the Connection Path the problem solver spots an opportunity and generates a new anchor to his beliefs by connecting different existing elements, by coincidence or by curiosity. This process usually involves new pieces of information or stimuli from different fields.
- The Creative Desperation Path can lead to a solution, when there is an impasse situation and the problem solver is stuck. In this situation discarding a weak belief or a flawed assumption can lead to the desired solution.

The three paths have not only different, but partly contradictory triggers. While the Contradiction Path builds on a weak anchor, the Creative Desperation Path eliminates the weak anchor and the Connection Path generates a completely new anchor, sometimes by sheer luck.

Creativity techniques or tools are usually categorized according to the principles of idea generation (Brem & Brem 2013, p. 28). Creativity techniques usually "provide a structured way […] to create interesting and eventually innovative concepts and solutions" (Ahmed & Shepherd 2010). To do this, creativity techniques contain a closed set of rules and instructions for the thinking which promote the generation of ideas. The rules of creativity techniques are set in such a way that they cause the application of idea-inspiring heuristic principles (Geschka 2013, p. 27). Thus, a categorization of creativity techniques should reveal the main creative heuristics underlying creativity techniques.

One prominent categorization is the structure proposed by Geschka and colleagues (Geschka 2013, p. 37, Geschka & Lantelme 2005, p. 324, Geschka & Zirm 2011, p. 292) (see fig. 2). The principles distinguished are free association, structured association, configuration, confrontation and imagination. While free association uses the mutual inspiration of different participants, structured association prescribes a set of rules or different perspectives to direct thinking into fruitful directions. Configuration uses the combinatorial possibilities of existing solution elements, confrontation evokes forced connections to elements extraneous to the problem and imagination makes use of the imaginative power of visual thinking (Brem & Brem 2013, p. 29). The core of these techniques is to break out of fixed mental routines by generating new perspectives, using further information and changing the problem frame (Geschka & Lantelme 2005, p. 324).

Some authors and researches focus solely on the principle of *combination*, since a combination of different mental patterns or a connection of mental concepts and stimuli of the environment is often at the heart of creative thought. Usually concepts from different categories are combined leading to “cross-fertilization” between different disciplines or fields (Sawyer 2012, p. 115). Koestler (1967, p. 35) named the combinatorial act of connecting elements from different contexts “Bisociation”: “I have coined the term `bisociation´ in order to make a distinction between routine skills of thinking on a single `plane´, as it were, and the creative act which […] always operates on more than one plane. The former may be called single-minded, the latter a double-minded, transitory state of unstable equilibrium where the balance of both emotion and thought is disturbed.”

Figure 2: Groups of Creativity Techniques

Idea-Generating Principle	Creativity Techniques (Examples)
Free Association	• Brainstorming • Brainwriting • Mindmapping
Structured Association	• De Bono´s Six Thinking Hats • Walt Disney´s Creative Thinking Technique • Checklists, e.g. SCAMPER
Configuration	• Morphological Box • Attribute Listing
Confrontation	• Synectic Excursion • Confrontation with pictures / words • TIPS-Principles
Imagination	• Take a picture of the problem • Try to become the problem

Source: Brem & Brem 2013, p. 29, Geschka 2013, p. 37, Geschka & Lantelme 2005, p. 324, Geschka & Zirm 2005, p. 292, own translation

Rothenberg (2014) distinguishes between three cognitive creative processes in scientific creativity all related to combinatorial processes:

- Sep-con articulation "consists of conceiving and using concomitant separation (SEP) and connection (CON)" (Rothenberg 2014, p. 1). This process mainly operates on part and whole effects, i.e. dismantling something into its components and re-assembling it in a new and surprising way.
- The Homospatial process is described as "actively conceiving two or more discrete entities occupying the same space or spatial location" (Rothenberg 2014, p. 41). Spatial effects which are superimposed include shapes, patterns, distances and dimensions, and the Homospatial process leads to new scientific metaphors and new identities.
- The Janusian process can be defined as "actively conceiving multiple opposites or antitheses simultaneously" (Rothenberg 1996, p. 207). The addressed opposites refer to logical and temporal effects and lead to the discovery of new and valuable phenomena (Rothenberg 2014, p. 28). Rothenberg (1987) shows that the Janusian process is at the core of many scientific breakthrough developments.

Sep-con articulation, Homospatial process and Janusian process can work in conjunction and can occur at several points in the creative undertaking.

With regard to *inventions* Weber (1992a) distinguishes between Single-Invention Heuristics, Multiple-Invention Heuristics and Transformational Heuristics. While Single-Invention Heuristics apply to one artifact, Multiple-Invention Heuristics involve several artifacts which are linked or joined. Transformational Heuristics work by abstracting and then transforming one element of the artifact. In another publication Weber (1992b) distinguishes between Inventing with Joins, Invention by Adding Features, Invention by Refinement and Invention by Abstraction & Transformation as heuristic principles. While Inventing with Joins contains several heuristics using combinations and connections, Invention by Adding Features encompasses several heuristics to add new functions to an existing product. Invention by Refinement just contains the Fine-Tuning Heuristic stating that "An inventor should find the direction that evaluation criteria move in, and try to anticipate the next step" (Weber 1992b, p. 229). Invention by Adding Features and Invention by Refinement are also included in the structure of Weber (1992a) as Single-Invention Heuristics. Invention by Abstraction & Transformation is the same as Transformational Heuristics, and Inventing with Joins corresponds to Multiple-Invention Heuristics to a large extent.

Weber & Perkins (1989) develop a framework of heuristics for the invention of artifacts and ideas containing a Frame Heuristic and several Within-Frame Heuristics and Between-Frame Heuristics. The Frame Heuristic provides a promising artifact or idea as a starting point and represents it as a frame for further inventive activities. The heuristics of the other categories work on this frame to improve it. The heuristics of Weber & Perkins (1989) show a big overlap to the heuristics of Weber (1992a) and Weber (1992b). The category Within-Frame Heuristics largely corresponds to the categories Single-Invention Heuristics and Transformational Heuristics, and the category Between-Frame Heuristics largely corresponds to the category Multiple-Invention Heuristics.

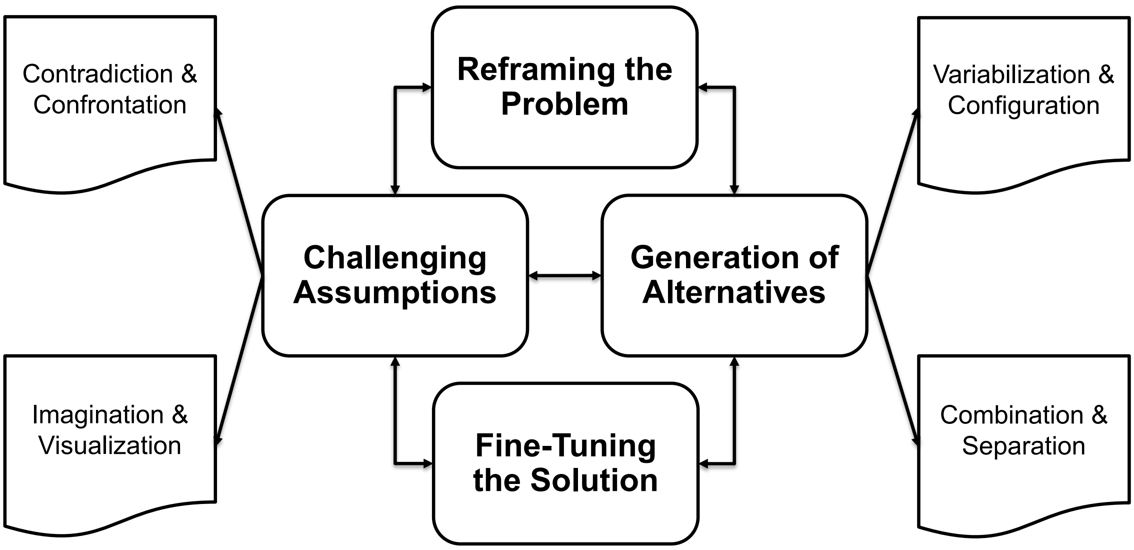
Another set of heuristics called “Modern Heuristics” is proposed by Polya (1988, p. 130). It includes Variation of the Problem, Decomposing and Recombining, Generalization, Specialization, Analogy, Auxiliary Elements and Auxiliary Problems as heuristic principles. Apart from Analogy which is similar to free association as a creative technique and Decomposing and Recombining which is reminiscent of the Sep-Con Articulation by Rothenberg (2014) this set of heuristics contains many rules to restructure the problem, i.e. to vary the problem, to specialize or generalize the problem or to add auxiliary elements or problems. Lists of the heuristics of Weber (1992a), Weber (1992b), Weber & Perkins (1989) and Polya (1988) are given in the appendix.

3.3 Framework for Creative Heuristics

From the literature analysis and the considerations about creative heuristics so far a framework for creative heuristics is proposed which is displayed in fig. 3. The purpose of this framework is not to provide a fool-proof recipe for invention, but to give a comprehensive overview over the effects of heuristics of medium generality which might be used for a creative undertaking especially for an invention. This framework can then be used to classify existing heuristics. After that it can be utilized as a toolbox for inventive activities.

The framework is based on the two basic principles of lateral thinking by de Bono (1990): generation of alternatives and challenging of assumptions. It is complemented by the elements "Reframing the Problem" and "Fine-Tuning the Problem". "Reframing the Problem" is a necessary element in creative problem solving and specifically addressed in the approach by Polya (1988). As Norman (2013, p. 217) writes: "One of my rules in consulting is simple: never solve the problem I am asked to solve […] Because, invariably, the problem I am asked to solve is not the real, fundamental, root problem". Reframing or restructuring a problem can be necessary when the problem solver encounters difficulties especially when he gets stuck in an impasse, when he finds novel pieces of information or gets novel stimuli or when he suffers from information overload (Perkins 2000, p. 133). "Fine-Tuning the Problem" is based on the Fine-Tuning Heuristic by Weber (1992a and 1992b) and is seen by Weber & Dixon (1989, p. 300 f.) as one of the heuristics applicable for a wide invention context. Fine-Tuning is usually a second step after the first creative idea to adjust it for better performance (Weber 1992a).

Figure 3: Framework of Creative Heuristics



Source: Own illustration

The generation of alternatives can be achieved by "Variabilization & Configuration" and/or by "Combination & Separation". It is incorporated in the connection path of Klein (2014, p. 104) where the problem solver has to spot an implication either through connection or through coincidence and curiosity. The principle of configuration is an idea-generating principle of creativity techniques (Geschka 2013). Furthermore the principle of variabilization is a central feature of Single-Invention Heuristics by Weber (1992a) respectively Within-Frame Heuristics by Weber & Perkins (1989). In particular it is related to the Make-Variable Heuristic of Weber (1992a) respectively Principle 2 (Variabilization) of Weber & Perkins (1989).

The principle of combination is mentioned in all of the described frameworks of principles. Surprisingly it is not directly mentioned as an idea-generating principle of creativity techniques. It can be assumed that it is implicitly included in the principle confrontation as the examples of creativity techniques in this category not only demand configuration but also combination (see chapter 3.2). Some approaches are solely based on combination and separation such as Koestler (1967) or Rothenberg (2014).

Challenging assumptions can be achieved by “Contradiction & Confrontation” and by “Imagination & Visualization”. Contradiction is a defining feature of an inventive problem and also of the inventive approach of TRIZ (see chapter 2.2). It is also an idea-generating principle of creativity techniques in methods such as Synectic Excursion (Geschka 2013). The principle “Contradiction & Confrontation” includes both the contradiction path and the creative desperation path of Klein (2014, p.104) where the problem solver has to find an inconsistency or escape an impasse. In these paths either a weak anchor is discarded or a weak anchor is used to build a new insight and usually an old anchor of commonplace wisdom is discarded. So both of these paths are about discarding unnecessary or inadequate anchors and are treated as one in this framework.

Imagination is not mentioned by any of the frameworks in chapter 3.2 with the exception of the idea-generating principles of Geschka (2013). This is surprising as imagination and visualization are reported by many inventors as a central approach, amongst them famous and often-cited accounts of August Kekulé about his discovery of the ring-structure of benzene (see e.g. Koestler 1967, p. 118), Albert Einstein in his contribution to Ghiselin (1985, p. 32 ff.) and Nikola Tesla in his autobiography (Tesla 2016, p. 5 ff.). The German INNCH study (2014, p. 23 ff.) found that imagination and visualization in the form of sensory-aesthetic thinking is a core skill of inventors, scientists and artists alike.

The described framework can be used as a toolbox with different phases. Usually the creative process starts with a problem definition. Then ideas are generated via generating alternatives and/or challenging assumptions. If this approach is successful the solution can then be fine-tuned. If it is unsuccessful, the problem solver can try to reframe the problem to find a better point of departure for a solution. The cycles between the phases allow for a flexible use of either problem reframing or solution fine-tuning. In idea generation the problem solver can switch between generating alternatives or challenging assumptions.

4 Allocating Creative Heuristics to the Framework

"Nothing is more important than to see the sources of invention which are, in my opinion, more interesting than the inventions themselves."
Gottfried Wilhelm Leibnitz, philosopher and mathematician
(cited in Polya 1988, p. 123)

In this chapter heuristics from the literature are allocated to the principles of the framework described in chapter 3.3. Creative heuristics for generating alternatives or challenging assumptions are briefly described and matched to the underlying principle. For the reframing of problems a field of opportunities is proposed specifically designed for industrial products. All the heuristics allocated in this chapter are described in detail in the appendix.

4.1 Creative Heuristics for Generating Alternatives

The main approach behind the principle "Generation of Alternative" is to go for quantity of ideas so as to also generate highly unusual ideas. For this it is advisable to defer judgement and select the best options in a second step (de Bono 1999, p. 55 ff.). Klein (2014, p. 104) refers to it as the connection path where the problem solver has to spot an implication. Heuristics help to generate alternatives by prescribing promising search areas or directions and, thus, limiting the number of possible paths. For this reason free association is not included.

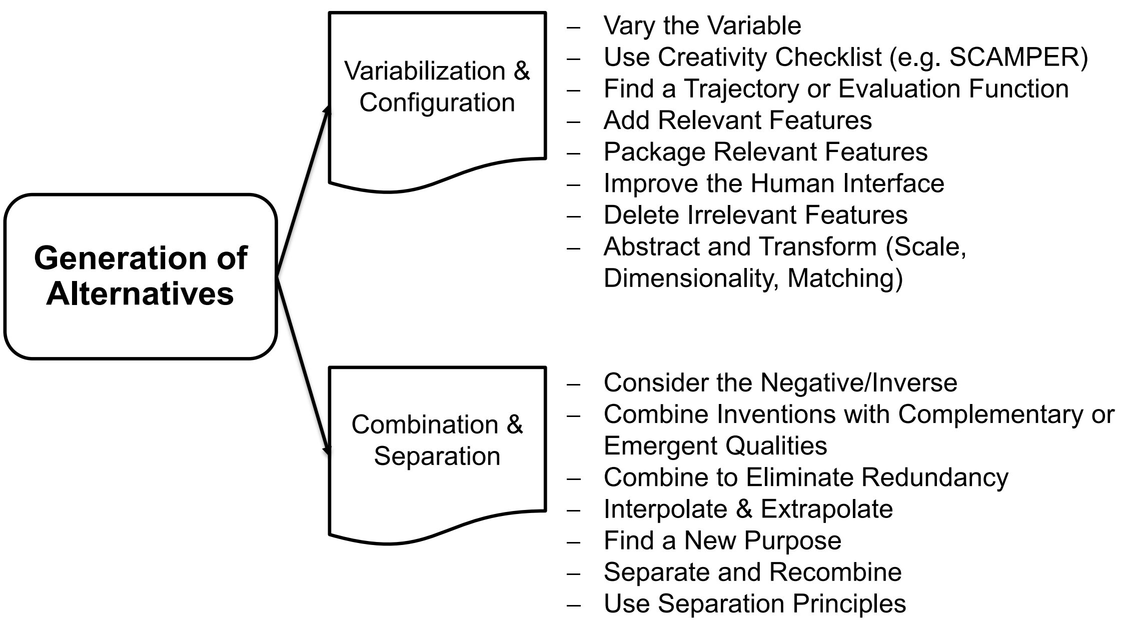
In the category "Variabilization & Configuration" the main heuristic is the Make-Variable Heuristic by Weber (1992a) respectively Principle 2 (Variabilization) by Weber & Perkins (1989). For a given product variables are created as potential dimensions of variation whose values are then changed to generate new inventions. This approach is also called "Vary the Variable" (Boden 1996b, p. 91) or "Choice of Entry Point and Attention Areas" (de Bono, 1999, p. 154 ff.). The change of the variable can be guided by an evaluation function as described by Principle 3 of Weber & Perkins (1989). The Repeated-Element

Heuristic by Weber (1992a) is a special case of variabilization. Creativity checklists such as SCAMPER (Eberle 1996, see appendix) can be used for this principle.

Furthermore all heuristics related to addition and deletion of features belong to this category, e.g. Feature Addition Heuristic and Feature Deletion Heuristic by Weber (1992a) and all heuristics in Invention by Adding Features by Weber (1992b). Features can be added to package functionality into the same structure (Packaging Heuristic), to improve the human interface (Interface Heuristic), to simply increase functionality (Slot Addition Heuristic) or to avail of an opportunity (Opportunity Heuristic) (Weber 1992b). Adding features has to be done with care so as not to overload a product with functionalities. Complexity of an invention is a potentially inhibiting factor of diffusion into a market (Rogers 2003, p. 257). Norman (2013, p. 262) calls the tendency to overload a product with new features “Featuritis”.

A further possibility is to abstract certain features of elements of an invention and to transform them according to scale, dimensionality or matching (deterministic or probabilistic). This refers to the Transformational Heuristics by Weber (1992a), the Abstraction Heuristic by Weber (1992b) and Principles 7 and 8 by Weber & Perkins (1989).

Figure 4: Creative Heuristics for Generating Alternatives



Source: Own illustration

To the category "Combination & Separation" belong all heuristics which combine, join or link several inventions or functions of inventions. Among these heuristics the Inverse Heuristic respectively Joining an Invention with its Inverse (Weber 1992a and 1992b, Weber & Perkins 1989) seems to be a powerful tool often used by inventors. It is also called "Consider the Negative" (Boden 1996b, p. 91). Other heuristics in this category lead to combinations with complementary or emergent qualities (Complement Heuristics, Emergent Function Heuristic) e.g. to avoid switching (Switching (Avoidance) Heuristic, Compacting Heuristics) or to deliver a better performance (Specialization Heuristic) and to combinations to eliminate redundancies (Shared-Property Heuristic or Overlap Heuristic) (Weber 1992a and 1992b). Principles 10, 12, and 13 of Weber & Perkins (1989) also belong to this group. Furthermore inventors can look for missing steps in a sequence of inventions and interpolate or extrapolate, see e.g. Interpolation Heuristic and Extrapolation Heuristic by Weber (1992b) and Principles 5 and 6 by Weber & Perkins (1989).

Especially for new materials or preliminary products the New-Purpose Heuristic can be applied. This heuristic advises to list all properties of a new material and to then try and find applications demanding one or several of these properties. This approach is also used in Technology Management to analyze the potential of a new technology (Spath, Linder & Seidensticker 2011, p. 66 f.). For parts or components of an invention the analogous heuristic is the Multiple Function Heuristic by Weber (1992b).

Furthermore heuristics using separation belong to this category as Decomposing & Recombining by Polya (1989), Principle 11 (Unjoin) by Weber & Perkins (1989) and the four separation principles of the TRIZ[5] approach – separation in space, separation in time, separation through change of conditions or state and separation within an object and its parts (Zobel 2009, p. 234 ff., see also appendix).

4.2 Creative Heuristics for Challenging Assumptions

One element of challenging assumptions is "Contradiction & Confrontation" which roughly corresponds to the contradiction path and the creative desperation path by Klein (2014, p. 104). A core approach to confront a company and its product is described by

[5] See footnote 2.

Bodell (2011, p. 50 ff.) as “Kill the Company” in her identically named book. In this approach employees of a company take an outside-in approach and try to destroy the company with new and improved product offerings or business models. This way employees are less inhibited to challenge deep-seated assumptions about the business environment and uncomfortable truths about their own company. The same exercise can be used to “Kill the Product” to radically challenge current product offerings. In a more general way Bodell (2011, p. 193 ff.) advises to use “Assumption Reversal” and just consider the opposite of current assumptions. Similar recommendations are given by de Bono (1999, p. 108 ff. and p. 124 ff.) called “Reversal Method” and “Dominant Ideas and Critical Factors”.

Confrontation is also an idea-generating principle of creativity techniques (Geschka 2013) which is sometimes termed Forced Connection (Bodell 2011, p. 191 ff.). Forced connection can be done visually or verbally. For visual confrontation pictures are used as confrontational elements. In verbal confrontation concrete terms from a different context than the one of the problem are connected to the problem. These terms can be randomly selected. The main aim is to free people from preconceived ideas (Geschka & Zirm 2011, p. 296).

Another way to use confrontation is to describe the ideal solution to a problem. The ideal final result (IFR) is a component of the TRIZ[6]-approach, but can also be used as a separate tool to challenge assumptions about a given product (see e.g. the principle “From Impossible to Possible” in Bodell 2012, p. 182 ff.). The ideal final result describes the best conceivable outcome of the inventive process with the most convenient conditions, regardless of wether this result is realistically achievable at the moment or not (Koltze & Souchkov 2011, p. 32 ff.).

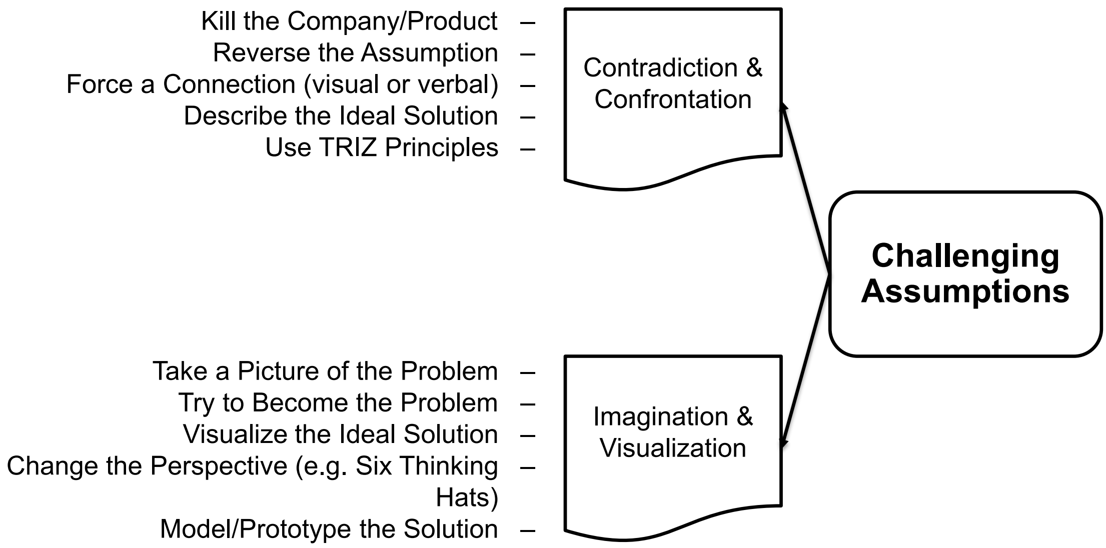
The entire approach of TRIZ is a way to overcome contradictions of inventive problems (see chapter 2.2). The central idea of TRIZ is to take a specific problem and turn it into an abstract problem. In the abstract problem a contradiction is detected, i.e. incompatible requirement of two parameters: While one parameter is improved the other one deteriorates and vice versa. So the contradiction has to be removed to achieve the ideal result. For this TRIZ offers combinations of 39 parameters arranged as a contradiction matrix.

[6] See footnote 2.

For each possible contradiction between two of the 39 parameters TRIZ offers 40 inventive heuristics – the 40 TRIZ Principles – to overcome said contradiction (see appendix). These principles supply an abstract solution which has to be transformed into a specific solution for the specific problem (Deckert & Zobel 2010, p. 7 ff., Spath, Linder & Seidensticker 2011, p. 189 ff., Zobel 2009, p. 75 ff.).

The allocation of the TRIZ Principles in the heuristic framework is problematic as these principles include medium generality heuristics (e.g. Universality, Preliminary Action or "Blessing in Disguise") as well as very specific heuristics (e.g. Mechanical Vibration, Spheroidality-Curvature or Flexible Shells and Thin Films). Furthermore they include considerable overlap to heuristics which can also be used for generating alternatives (e.g. Segmentation, The Other Way Round or Parameter Changes). Nevertheless, since the entire approach of TRIZ aims at overcoming contradictions the TRIZ Principles have been allocated to this category.

Figure 5: Creative Heuristics for Challenging Assumptions



Source: Own illustration

The main idea of imagination and visualization is to use pictorial representations of a problem and/or its possible solutions (Geschka & Zirm 2011, p. 297). As described visual-aesthetic thinking and immersion can be seen as central components of the creativity of inventors and scientists (INNCH 2014, p. 23 ff.). In "Try to become the problem" the inventor projects himself into the problem situation to conceive possible solutions. In

"Take a picture of the problem" the problem solver analyzes the problem like a camera to sharpen his views for the causal relations of the problem (Geschka & Zirm 2011, p. 297). A variant of these heuristics is to visualize the ideal solution.

Another possibility for imagination is to take on different perspectives on a problem – either of main stakeholders, e.g. user of the product, seller of the product, innocent by-stander etc. or fixed perspectives such as the Six Thinking Hats by de Bono (1999) or the three roles of the Walt Disney Method (Geschka & Zirm 2011, p. 294). In this way the inventor imagines the possible thoughts, feelings, wants and needs of different possible stakeholders and tries to see the problem from their perspective. The immersion into the world of the customer is also used in approaches of Empathic Design (Mattelmäki, Vaajakallio & Koskinen 2013) and Design Thinking (Brown 2008).

Another heuristic from Design Thinking is to model or prototype the solution. A prototype does not need to look like a finished product. On the contrary a "quick and dirty"-prototype can help to visualize a solution while simultaneously being cheap. Furthermore an unfinished prototype invites people to make changes and corrections (Brown 2008, Kelley 2001). "Prototypes should command only as much time, effort, and investment as are needed to generate useful feedback and evolve ideas" (Brown 2008, p. 87). Tinkering and fiddling with models and prototypes in product development makes the customer experience of the product more tangible and helps to get important feedback of the functionality and effectiveness of an invention. This approach is called "action theory" which has led to a shift of focus in creative problem solving from contemplation to action (Sawyer 2012). It can lead to significant design improvements of inventions as the US-American company IDEO has successfully shown several times (Kelley 2001).

4.3 Reframing the Problem

Reframing the problem can be necessary at several points along the process of problem solving. Many authors (see e.g. Geschka 2005, Norman 2013, p. 164 ff., Michalko 2011, p. 41 ff.) stress the importance of a thorough problem analysis at the very beginning to determine the "real" problem to be solved. In root cause analysis the inventor asks "why"-questions several times to get to the core of the problem. This method is similar to the "5 Why"-technique of Lean Management. The newest version of the Creative Problem

Solving (CPS) approach includes a stage called "Framing the Problem" (Isaksen & Treffinger 2004, p. 95). During problem solving it can become necessary to restructure the problem when the inventor is stuck or upon novelty or overload (Perkins 2000, p. 133). Reframing in an industrial context of invention can be achieved by generalization or specialization with regard to the product offering or by taking into account auxiliary elements such as packaging or the competitive environment and auxiliary problems from other areas of the business model (see fig. 6).

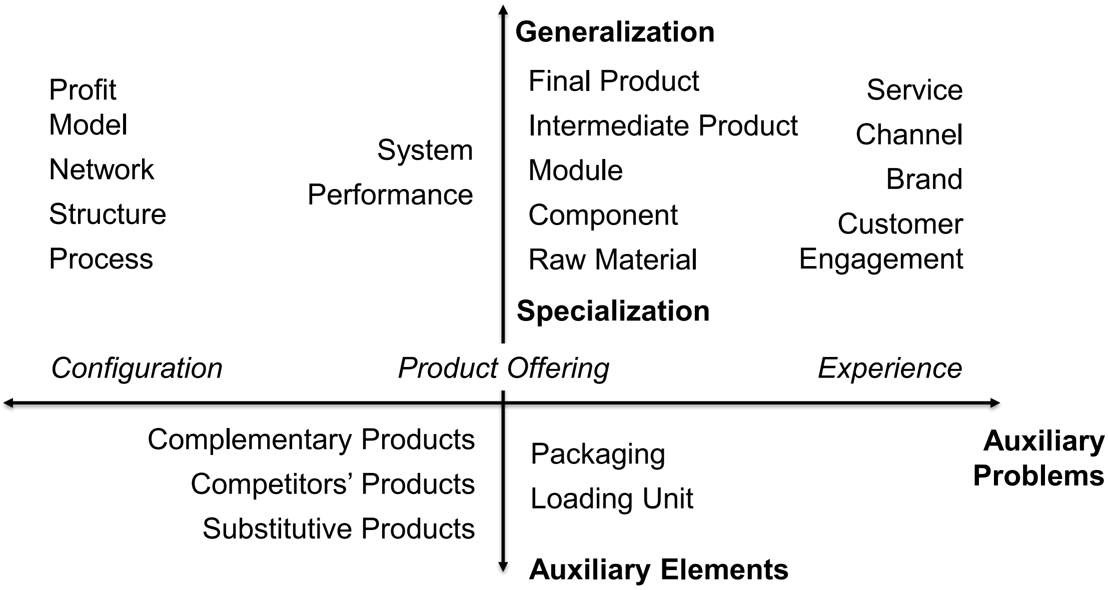
According to Polya (1989, p. 108 ff. and 190 ff.) Generalization and Specialization can be used to change the level of detail of a problem as a means for reframing the problem. For companies from the manufacturing sector this translates into understanding the product as a "holon" (Deckert 2016, p. 5 ff.). The term "holon" was coined by Koestler (1975, p. 48) "from the Greek holos = whole, with the suffix on which, as in proton or neutron, suggests a particle or part" for entities "which behave partly as wholes and wholly as parts". Transferred to an industrial product, the product can be either seen as an autonomous sellable unit or as a component of a larger entity, e.g. a more complex product or a business model. So the product can be either broken down into modules, components and raw materials to find a solution or it can be positioned into a wider context of the final product of which it is a part. Especially in a B2B-environment many products are preliminary materials or parts used to build other products. Eventually at the end of this value chain an Original Equipment Manufacturer (OEM) produces the final product which is sold to consumers (B2C-product).

According to Polya (1989, p. 50 ff.) an Auxiliary Problem is a kind of substitutive problem for the one the inventor intends to solve. For a company from the manufacturing sector the business model offers opportunities to substitute an inventive problem with a different type of problem. A business model can be defined as "the rationale of how an organization creates, delivers and captures value" (Osterwalder & Pigneur 2010, p. 14). In an industrial context a product can be seen as a part of the value proposition of a business model. Apart from the product offering the value creation of a business model includes customer segments, communication and distribution channels, customer relationships and revenue streams (Osterwalder & Pigneur 2010, p. 16 ff.). Conceiving a product in such a way can broaden the search space for possible solutions. A solution can be searched in the product offering, i.e. by improving the product performance or the product system. Apart from the product offering, a solution can also be searched in the configuration and the customer experience. Configuration includes the profit model of the product, the network of partners and suppliers as well as the structure and processes for producing and distributing the product. Customer experience contains services as a complement or as a substitution of the product, distribution and communication channels for the product, product branding and positioning as well as customer engagement (Keeley et al. 2013, p. 16 ff.).

According to Polya (1989, p. 46 ff.) an Auxiliary Element can be introduced to facilitate the search for a solution. Transferred to industrial products Auxiliary Elements can lie in packaging or the competitive environment. Packaging can be defined as a "unit which serves a packaging function such as the containment, protection, handling, delivery, storage, transport and presentation of goods" (ISO 21067 2015). Sales packagings serve a few key roles which can be used as a solution for certain inventive problems. These include protection & containment, environmental impacts & ethical implications, identification & marketing communication, user convenience & market appeal, cost and innovation (Simms 2012, p. 101 ff.). Products are usually not shipped out as single packages but in the form of loading units, e.g. pallets or containers. So a solution might be achieved by changing the packaging or the loading unit instead of the product.

Another Auxiliary Element is the competitive environment of the product which includes all competitor products and substitutive products. By a competitor analysis either the threat of substitution or further applications of an invention or a technology might be spotted (Pfeiffer et al. 1997, p. 69 ff.). The competitive environment furthermore contains complementary products (Geschka 2005, p. 388 ff.) which might be used to solve certain inventive problems.

Figure 6: Reframing the Problem



Source: Own illustration based on Geschka (2005), Polya (1989) and Keeley et al. (2013)

5 Conclusion

"For most people, innovative thinking has become
a one-time PowerPoint exercise reserved for the annual strategic plan."
Bodell (2012, p. xxi)

In the paper at hand a framework for creative heuristics was developed by analyzing existing approaches to heuristics and gaining insight. The framework is based on the two general principles "Generation of Alternatives" and "Challenging Assumptions" by de Bono (1999). So the framework combines the ideas that "quantity will breed quality" by Alex Faickney Osborn with the idea of Genrish Altshuller that "inventing is the resolution of technical contradictions". Each principle is split into two sub-principles: Generating alternatives can be achieved by "Variabilization & Configuration" and "Combination & Separation"; challenging assumptions by "Contradiction & Confrontation" and "Imagination & Visualization". Furthermore "Reframing the Problem" and "Fine-Tuning the Solution" complete the framework.

Creative heuristics from the literature about invention and innovation were allocated within the framework. These heuristics can help a problem solver to overcome fixation and other human biases, such as endowment effect and status quo-bias. Apart from that they offer promising search areas and directions and, thus, can transform a Klondike Space into a Homing Space. So the framework offers a toolbox for inventors. Furthermore it also offers phases to shift between in the inventive process. Typically an inventor would start by defining or framing the problem. Then he would tackle the problem by generating alternatives and/or challenging assumptions. If a promising solution is found, it is fine-tuned to improve its functionality. If the inventor gets stuck, he can turn back to reframe the problem. For companies of manufacturing industries several paths for reframing are offered including generalization and specialization of a product offering, auxiliary elements in the form of packaging and competitive environment and auxiliary problems of the business model. Finally the framework might be used in promoting creativity in engineering education as described by Cropley (2015, p. 168 ff.).

One limitation of the framework is that it is only a toolbox of heuristics with several phases, but not a fixed method with a step-by-step approach to the best solution. In fact it is hard to determine the effectiveness of the single heuristics in the framework. But the heuristics in the framework are proven by historical analysis of inventions or by accounts or observations of problem solvers. They have been tested by several creative people and found worthy to be included in their books and papers. Generally, heuristics can be seen as one way to solve creative problems (Perkins 1992, p. 247 ff.). Nevertheless, the framework cannot guarantee a good solution. It cannot even guarantee that the inventor finds a solution at all. So there is still room for chance insights triggered by random stimuli. But the application of the heuristics of the framework should increase the likelihood of success and turn a situation of sheer chance into a situation of a fair or good bet (see Perkins & Weber 1992, p. 320). Nevertheless, it might sometimes be advisable to ignore the heuristics: Sometimes the best heuristic to choose is to drop a heuristic.

Apart from that, creativity does not only depend on creative thinking skills which can be fostered by using creative heuristics. In the Componential Theory of Individual Creativity by Amabile (1996, p. 83 ff.) expertise in the respective domain and task motivation are also core components. Furthermore invention is not only determined by market pull or technology push. Admittedly it is right that customer needs are a basis for invention and that “necessity is the mother of invention”. Equally it holds true that technologies enable new products and arouse new needs in people so that “Sometimes invention is the mother of necessity” (Weber 1992a, p. 8). But it also seems to be the case that invention is an activity which is undertaken as an autotelic activity putting inventors into the flow channel, as the research by Csikszentmihalyi (1997) suggests. Or as Alex Faickney Osborn is supposed to have said: “Necessity may be the mother of invention, but fun is the father” (AZQuotes 2017).

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Appendix: Lists of Creative Heuristics

Weber (1992a, p. 88 ff.)

Single-Invention Heuristics	
Make-Variable Heuristic	Make or identify potential dimensions of variation, that is, create dimensions or variables where previously only fixed features or constants existed. Then begin to change the values of those variables to more closely approximate the desired goal, as determined by evaluative criteria […].
Repeated-Element Heuristic	Once an interesting component is discovered […] try copying or repeating it as often as necessary. It may be a suitable building block for more complex inventions.
Fine-Tuning Heuristic	After the right parts are in place, try to rearrange or tweak them for better performance. It is usually possible to improve something by getting all the variables in just the right configuration. To do this sensibly, it is important to have definitive evaluative standards in mind.
Variance Control Heuristic	Seek out variances that need to be controlled, from concrete quantities like water to abstract quantities like information. Then try to find improved methods of control in order to minimize range or to spread it out more evenly.
Feature Deletion Heuristic	See what features or dimensions you can delete from an invention and still have a viable product.
Feature Addition Heuristic	See what other features or dimensions you can add to a given product.
Multiple-Invention Heuristics: Linking	
Interpolation Heuristic	Look for intermediate states in a line of invention development. Some of these states may also be useful. […]
Extrapolation Heuristic	Look for trends in a line of invention development. Try to continue those trends to a next step. To do so may require the finding of new functions or purposes. Or it may simply be the idea of continuous improvement along a dimension that guides us.
New-Purpose Heuristic	Begin with a listing of the known properties of the new material. […] look for applications that require one or more of the properties that match those of our material. […]
Multiple-Invention Heuristics: Joining	
Inverse Heuristic	Try joining those tools or devices that undo the actions of one another. These are often useful combinations.
Complement Heuristic	Combine those tools or inventions that are used together in the same context. Do this especially if the separate inventions have complementary strengths and weaknesses […].

Shared-Property Heuristic	Whenever tools or devices share one or more attributes or parts, try to join them to eliminate redundancy, minimize size or space, or hold down overall cost.
Emergent Function Heuristic	When joining inventions, be on the watch for important new capabilities that are not present in either of the parent inventions. One of those functions is parallelism, the ability to use simultaneously the capabilities of each parent device.
Transformational Heuristics	
Scale Heuristic	Try changing the size of one or more components in an existing invention. Often a change in size scale will open up entirely new applications.
Dimensionality Heuristic	Try changing the dimensionality of one or more components in an existing invention. […]
Matching Heuristic	Try changing the basis of matching or linking between components, from deterministic to haphazard. The way components are linked together is a fundamental principle.

Weber (1992b, p. 221 ff.)

Inventing with Joins	
Complement Heuristic	Combine only those tools or ideas that are used in the same context.
Inverse Heuristic	Combine only those tools or ideas that are inverses of each other.
Overlap Heuristic	Join only those tools with partially overlapping parts, properties or functions.
Multiple Functions Heu-ristic	Find multiple functions for the same part.
Specialization Heuristic	Allow for different specific [functional components] as part of the same overall tool to maximize the fit between tool and task.
Compacting Heuristic	Join components tightly, so they are in a package and will not become separated or lost.
Switching Avoidance Heuristic	Cut down on the dead time between uses that results from having to look for a related tool and then switch to it.
Invention by Adding Features	
Slot Addition Heuristic	Increase functionality by adding features […].
Packaging Heuristic	Pack as much functionality as possible into the same structures and space.
Interface Heuristic	Develop a human interface, like a handle, that is comfort-able and that will enhance leverage and control.
Opportunity Heuristic	Here's a place that we can add a new function, so let's do it.
Invention by Refinement	
Fine-Tuning Heuristic	An inventor should find the direction that evaluation crite-ria move in, and try to anticipate the next step.
Invention by Abstraction and Transformation	
Abstraction Heuristic	[…] abstraction of a building block and subsequent spatial transformations of that building block […].

Weber & Perkins (1989)

The Frame Heuristic	
Principle 1 (Frame)	Given an artifact or idea that might provide a point of departure for invention, represent it as a frame with slots bound to the values characteristic of the thing or idea.
Within-Frame Heuristics	
Principle 2 (Variabilization)	Create variables in place of constants. Substitute a variety of values in slots to change the nature of a frame in order to reach a goal.
Principle 3 (Evaluation Function)	To guide oneself along a path of frames through invention space, construct an evaluation function that takes into account the invention or idea constraints […], the points of free variation […], and the overall purpose at hand.
Principle 4 (Extension of Terms)	Try to apply a given tool, procedure, rule, or method to entities that share many of the same slots and values with the original objects of interest, thereby expanding the domain of application by adding XOR terms.
Principle 5 (Interpolation)	If there are gaps or missing values between important working inventions or ideas, try to generate the filler […]
Principle 6 (Extrapolation)	If there is a possibility of an ordered class, try to extrapolate to an earlier or later member. If possible, try to consider limiting cases (such as zero or infinity).
Principle 7 (Scale and Dimensionality Changes)	Generate inventions and ideas by changing size scale and slots; and by moving between deterministic and probabilistic processes.
Principle 8 (AND Abstraction)	To become more abstract, drop slots (or treat them as Don't Cares).
Between-Frame Heuristics	
Principle 9 (Joining an Invention with its Inverse)	If an operation is interesting or powerful, look for its inverse, which may also be interesting and powerful. If necessary, change the definition of the domain so the inverse will work. The existence of an inverse will increase the range of inputs and outputs to and from an operation or process.
Principle 10 (Joins in General)	Use a frame Join operation to create general new entities that integrate the properties of the simpler components by combining simpler frames; at the same time, eliminate redundancies.
Principle 11 (Unjoin)	To understand a complex system, perform Unjoin in the search for functional subcomponents.
Principle 12 (Metaphor)	Generate possible ideas about a target domain by metaphorically borrowing selected slots from other model domains. If the fit is not satisfactory, try dropping slots from the target domain or the model domain to decrease constraint and increase abstraction.

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Principle 13 (Frame Comparison)	Determine differences and likenesses of frames, and notice the trajectory of their change as a suggestion of next steps in invention. This tells one what direction to move in the search space of possible inventions.

Polya (1988, p. 131)

Modern Heuristics	
Variation of the Problem	Desiring to proceed from our initial conception of the problem to a more adequate, better adapted conception, we try various standpoints and we view the problem from different sides.
Decomposing and Recombining	You decompose the whole into its parts, and you recombine the parts into a more or less different whole.
Generalization	Generalization is passing from the consideration of one object to the consideration of a set containing that object; or passing from the consideration of a restricted set to that of a more comprehensive set containing the restricted one.
Specialization	Specialization is passing from the consideration of a given set of objects to that of a smaller set, or of just one object, contained in a given set.
Analogy	Analogy is a sort of similarity. Similar objects agree with each other in some respect, analogous objects agree in certain relations of their respective parts. […] All sorts of analogy may play a role in the discovery of the solution and so we should not neglect any sort.
Auxiliary Elements	An element that we introduce in the hope that it will further the solution is called an auxiliary element.
Auxiliary Problem	Auxiliary problem is a problem which we consider, not for its own sake, but because we hope that its consideration may help us solve another problem, our original problem.

Eberle (1996, p.6)

SCAMPER	
Substitute	To have a person or thing act or serve in the place of an-other.
Combine	To bring together, to unite.
Adjust	To adjust for the purpose of suiting a condition of pur-pose.
Modify Magnify Minify	To alter, to change the form or quality. To enlarge, make greater in form or quality. To make smaller, lighter, slower.
Put to other uses	To have a person or thing act or serve in the place of an-other.
Eliminate	To remove, emit, or get rid of a quality, part, or whole.
Reverse Rearrange	To place opposite, to turn around. To change order or adjust, different plan, layout, or scheme

TRIZ Principles (SolidCreativity 2014)

40 TRIZ Principles	
Segmentation	Divide an object into independent parts. Make an object easy to disassemble. Increase the degree of fragmentation or segmentation.
Taking out	Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.
Local Quality	Change an object's structure from uniform to non-uniform, change an external environment (or external influence) from uniform to non-uniform. Make each part of an object function in conditions most suitable for its operation. Make each part of an object fulfill a different and useful function.
Asymmetry	Change the shape of an object from symmetrical to asymmetrical. If an object is asymmetrical, increase its degree of asymmetry.
Merging	Bring closer together (or merge) identical or similar objects, assemble identical or similar parts to perform parallel operations. Make operations contiguous or parallel; bring them together in time.
Universality	Make a part or object perform multiple functions; eliminate the need for other parts.
Nested Doll	Place one object inside another; place each object, in turn, inside the other. Make one part pass through a cavity in the other.
Anti-Weight	To compensate for the weight of an object, merge it with other objects that provide lift. To compensate for the weight of an object, make it interact with the environment (e.g. use aerodynamic, hydrodynamic, buoyancy and other forces).
Preliminary Anti-Action	If it will be necessary to do an action with both harmful and useful effects, this action should be replaced with anti-actions to control harmful effects. Create beforehand stresses in an object that will oppose known undesirable working stresses later on.
Preliminary Action	Perform, before it is needed, the required change of an object (either fully or partially). Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.
Beforehand Cushioning	Prepare emergency means beforehand to compensate for the relatively low reliability of an object.

Equipotentiality	In a potential field, limit position changes (e.g. change operating conditions to eliminate the need to raise or lower objects in a gravity field).
The Other Way Round	Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it). Make movable parts (or the external environment) fixed, and fixed parts movable. Turn the object (or process) 'upside down'.
Spheroidality – Curvature	Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones; move from flat surfaces to spherical ones; from parts shaped as a cube (parallelepiped) to ball-shaped structures. Use rollers, balls, spirals, domes. Go from linear to rotary motion, use centrifugal forces.
Dynamics	Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition. Divide an object into parts capable of movement relative to each other. If an object (or process) is rigid or inflexible, make it movable or adaptive.
Partial or Excessive Actions	If 100 percent of an object is hard to achieve using a given solution method then, by using 'slightly less' or 'slightly more' of the same method, the problem may be considerably easier to solve.
Another Dimension	To move an object in two- or three-dimensional space. Use a multi-story arrangement of objects instead of a single-story arrangement. Tilt or re-orient the object, lay it on its side. Use 'another side' of a given area.
Mechanical Vibration	Cause an object to oscillate or vibrate. Increase its frequency (even up to the ultrasonic). Use an object's resonant frequency. Use piezoelectric vibrators instead of mechanical ones. Use combined ultrasonic and electromagnetic field oscillations.
Periodic Action	Instead of continuous action, use periodic or pulsating actions. If an action is already periodic, change the periodic magnitude or frequency. Use pauses between impulses to perform a different action.
Continuity of Useful Action	Carry on work continuously; make all parts of an object work at full load, all the time. Eliminate all idle or intermittent actions or work.
Skipping	Conduct a process, or certain stages (e.g. destructible, harmful or hazardous operations) at high speed.

“Blessing in Disguise” or “Turn Lemons into Lemonade”	Use harmful factors (particularly, harmful effects of the environment or surroundings) to achieve a positive effect. Eliminate the primary harmful action by adding it to another harmful action to resolve the problem. Amplify a harmful factor to such a degree that it is no longer harmful.
Feedback	Introduce feedback (referring back, cross-checking) to improve a process or action. If feedback is already used, change its magnitude or influence.
Intermediary	Use an intermediary carrier article or intermediary process. Merge one object temporarily with another (which can be easily removed).
Self-Service	Make an object serve itself by performing auxiliary helpful functions. Use waste resources, energy, or substances.
Copying	Instead of an unavailable, expensive, fragile object, use simpler and inexpensive copies. Replace an object, or process with optical copies. If visible optical copies are already used, move to infrared or ultraviolet copies.
Cheap Short-Living Objects	Replace an inexpensive object with a multiple of inexpensive objects, comprising certain qualities (such as service life, for instance).
Mechanics Substitution	Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means. Use electric, magnetic and electromagnetic fields to interact with the object. Change from static to movable fields, from unstructured fields to those having structure. Use fields in conjunction with field-activated (e.g. ferromagnetic) particles.
Pneumatics and Hydraulics	Use gas and liquid parts of an object instead of solid parts (e.g. inflatable, filled with liquids, air cushion, hydrostatic, hydro-reactive).
Flexible Shells and Thin Films	Use flexible shells and thin films instead of three dimensional structures Isolate the object from the external environment using flexible shells and thin films.
Porous Materials	Make an object porous or add porous elements (inserts, coatings, etc.). If an object is already porous, use the pores to introduce a useful substance or function.
Color Changes	Change the color of an object or its external environment. Change the transparency of an object or its external environment.
Homogeneity	Make objects interacting with a given object of the same material (or material with identical properties).

Discarding and Recovering	Make portions of an object that have fulfilled their functions go away (discard by dissolving, evaporating, etc.) or modify these directly during operation. Conversely, restore consumable parts of an object directly in operation.
Parameter Changes	Change an object's physical state (e.g. to a gas, liquid, or solid.). Change the concentration or consistency. Change the degree of flexibility. Change the temperature.
Phase Transitions	Use phenomena occurring during phase transitions (e.g. volume changes, loss or absorption of heat, etc.).
Thermal Expansion	Use thermal expansion (or contraction) of materials. If thermal expansion is being used, use multiple materials with different coefficients of thermal expansion.
Strong Oxidants	Replace common air with oxygen-enriched air. Replace enriched air with pure oxygen. Expose air or oxygen to ionizing radiation. Use ionized oxygen. Replace ozonized (or ionized) oxygen with ozone.
Inert Atmosphere	Replace a normal environment with an inert one. Add neutral parts, or inert additives to an object.
Composite Materials	Change from uniform to composite (multiple) materials.

Separation Principles (Zobel 2009, p. 234 ff., own translation)

4 Separation Principles	
Separation in Space	Contradictory objects, functions or features have to be separated spatially so that the desired useful effect only takes place in a certain spatial area and the rest of the system remains unaffected.
Separation in Time	Contradictory objects, functions or features have to be separated in time so that the desired activity is only conducted at a certain time. The functions have to be divided in time so that the contradictory conditions cannot collide anymore.
Separation through Change of Conditions or State	The separation of contradictory requirements take place due to the modification of conditions under which a useful and at the same time unnecessary or harmful process operates. The system has to be transferred to a different state (solid, liquid, gaseous). Certain intermediate states are also interesting, e.g. soft, elastic, viscous.
Separation within an Object and its Parts	Subsystems exercise a function contradicting the total system without impairing the functional requirements to the total system. Subsystems should be able to exercise functions relevant for the total system which could not be exercised by the total system without the help of the subsystem.

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