TRIZ INVENTIVE PRINCIPLES

40 principles with 160 inventive operators

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The analysis of several thousand patents led to the conclusion that inventive engineering problems and technical contradictions in all kinds of industrial sectors could be solved by a limited number of basic Inventive Principles (Altshuller, 1984). The modern Theory of Inventive Problem Solving TRIZ (VDI 4521) contains 40 basic Inventive Principles (IP). These principles are simple to use or modify and can be easily integrated in brainstorming or daily engineer's work. One established part of industrial practice is the composition of the specific groups of principles for solving different kinds of problems (Livotov, Petrov, 2011), for example:

- Statistically most often used principles for engineering problems (Table 1)
- Most suitable principles for solving product design problems (Table 1)
- Principles for creative cost reduction (Table 2; IP-No 1, 2, 6, 10,16, 20, 25, 26, 27)
- Principles for fast prediction of technological evolution (IP-No 1, 5, 6, 15, 17, 19, 23, 25, 28, 29, 30, 31)

Based on interdisciplinary experience of TRIZ application in the industrial companies in the last 25 years the following general order in the application of 40 Inventive Principles can be recommended for idea generation and problem solving. This brochure presents an update of the 40 Inventive Principles (Livotov, Chandra et al, 2019) extending the original version (Altshuller, 1984) with additional 70 sub-principles, resulting in the advanced set of 160 sub-principles, regarded as elementary inventive operators.

Table 1. Recommended order for application of 40 Inventive Principles.

Group 1: Statistically strongest principles deliver solutions to approx. 50% of all problems	
35. Transformation of the physical and chemical properties	19. Periodic action
10. Prior useful action	3. Local quality
1. Segmentation	17. Shift to another dimension
28. Replacement of mechanical working principle	13. Inversion
2. Leaving out / Trimming	18. Mechanical vibration
15. Dynamism and adaptability	26. Copying and modelling
Group 2: Principles for solving design problems and performing auxiliary functions	
6. Universality	40. Composite materials
5. Combining	24. Mediator
30. Flexible shells or thin films	14. Sphericity and Rotation
29. Pneumatic or hydraulic constructions	23. Feedback and automation
7. Nesting / Integration	31. Porous materials
8. Anti-weight	25. Self-service
4. Asymmetry	
Group 3: Principles for specific problems, for example in process engineering	
16. Partial or excessive action	39. Inert environment
27. Disposability, cheap short-living objects	37. Thermal expansion
20. Continuity of useful action	36. Phase transitions
32. Changing colour	38. Strong oxidants
21. Skipping / Rushing through	34. Rejecting and regenerating parts
11. Preventative measure	12. Equipotentiality
33. Homogeneity	9. Prior counteraction of harm
22. Converting harm into benefit	

References:

1. Altshuller G.S. (1984) Creativity as an exact science: the theory of the solution of inventive problems, Gordon and Breach Science Publishers.
2. VDI Standard 4521 (2016-2021) Inventive Problem Solving with TRIZ. The Association of German Engineers (VDI), Beuth, Duesseldorf.
3. Livotov, P., Petrov, V. (2011): TRIZ Innovation Technology - Product Development and Inventive Problem Solving. Handbook. Berlin, TriS Europe.
4. Livotov P., Chandra Sekaran A.P., Law R., Mas'udah, Reay D. (2019) Systematic Innovation in Process Engineering: Linking TRIZ and Process Intensification. In: Chechurin L., Collan M. (eds) Advances in Systematic Creativity. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-319-78075-7_3.

Table 2. 40 TRIZ Inventive Principles with 160 sub-principles

IP-N	TRIZ Principle	Sub-principles (Livotov, Chandra et al., 2019)	Examples (Livotov. P., Petrov. V., 2011)
1	**Segmentation**	a) Divide the object into independent objects or parts. b) Design the object to be sectional or dismountable. c) Increase the object's degree of fragmentation or segmentation: reduce size up to granules and powder, micro- and nano-level, molecules and atoms. d) Divide the function of the object or system into independent sub-functions. e) Divide the process steps into sub-steps, make two or more process steps instead of one	*Example 1: A cargo ship is made up of several identical sections. The length of the ship can be varied by adding or removing sections as required.* *Example 2: Modular design of an appliance (TV set, computer etc.) not only simplifies fault diagnosis and repair, but also facilitates the recycling of the product.* *Example 3: Two-component adhesive. The two components are mixed together just before being used. The separate components can be stored almost indefinitely.* *Example 4: Shortly before the relocation of a public library in Scotland, the director asked all readers in the town to borrow books and return them later to the new premises.*
2	**Leaving out / Trimming**	a) Take out or remove the disturbing parts or substances from the system. b) Check which system components, parts or substances can be omitted. c) Take out or remove the disturbing functions from the system. Check which functions can be omitted. d) Take out or remove one of the process steps e) Extract or single out the only one necessary part, substance, property or function from the system.	*Example 1: In order to reduce the risk of an unwanted explosion fuses and explosives are always stored separately. The two are only assembled together shortly before being used.* *Example 2: A geostationary communication satellite in orbit carries all of the equipment of a terrestrial television transmitter. There is now no longer the need for a huge tower.*
3	**Local quality**	a) Change the uniform structure or properties of an object to a non-iniform. b) Change the uniform structure or properties of surrounding medium (external environment) to non-iniform. c) The various parts of the object should fulfil different functions. d) Each part of the object should function under conditions which are most suitable for its operation. e) Different parts of the object can have opposite properties:, e.g. one part - hot, another part - cold.	*Example 1: To combat dust in mines, a fine spray of water is applied directly to the working parts of the machinery. The smaller the droplets are, the greater is the effect in combating the dust. The small water droplets however cause a mist to form in the immediate area, which reduces the visibility. To prevent mist of* small water droplets, the fine spray is surrounded by a curtain of larger droplets from a different nozzle.* *Example 2: Creating a self-centring form tool by using a temperature field. In the production of seamless tubes, a hot, cylindrical billet is penetrated by a pointed forming tool (piercing plug). In order to prevent the piercing plug from wandering inside the tube, the outside of the tube is cooled. This causes a favourable temperature distribution within the tube: cold (hard) on the outside – hot (soft, easily penetrable) towards the centre.*
4	**Asymmetry**	a) Replace the symmetrical shape or property of an object with one that is asymmetrical. b) If the object is already asymmetrical, increase its degree of asymmetry. c) Convert the asymmetrical shape or property of an object back to symmetrical one.	*Example 1: An asymmetric tyre with a stronger outside wall can better withstand an impact when hitting a curb (US Pat. 3435875).* *Example 2: Semiconductors: a diode allows a current to flow in only one direction.* *Example 3: If components are only slightly asymmetrical, they can easily be mixed up during assembly. To avoid this, the asymmetric design should be clearly obvious to avoid assembly errors.*
5	**Combining**	a) Combine identical objects in space to perform parallel operations. b) Combine functions or process steps in time to perform parallel or contiguous operations. c) Combine similar objects with different characteristics, properties or parameters. d) Combine different objects complementing each other and enhancing positive properties. e) Combine objects with competing, alternative, or opposing properties, e.g. caustic and acid.	*Example 1: Twin microscope. The adjusting is performed by one person, a second person can simultaneously observe and record.* *Example 2: Tandem bicycle. The drive sprockets of both cyclists are synchronized by a common chain.* *Example 3: The bucket of an excavator is additionally equipped with steam nozzles to soften the ground whilst digging.*

6	**Universality**	a) Make a part or object universal, performing multiple functions, and thus eliminate unnecessary objects. b) Make a process universal, for example suitable for different substances, conditions, operations etc.	*Example 1: The handle of a briefcase also serves as a chest expander.* *Example 2: A printer that can also be used as a scanner, copier, and fax machine.* *Example 3: 2-in-1 shampoos fulfil the functions of two components: shampoo and conditioner.*
7	**Nesting / Integration**	a) Place an object inside another one, which, in turn, is placed inside a third object and so on (Nested Doll principle). b) An object is passed through the cavities in another object. c) Telescopic objects or systems.	*Example 1: Ultrasonic-concentrator in the form of hollow cones (truncated cones) stacked one inside another.* *Example 2: Telescope: telescopic hydraulic cylinder, telescopic antenna etc.* *Example 3: The exchangeable "bits" of an universal screwdriver are stored in its handle.*
8	**Anti-weight**	a) Compensate the object's weight by counterweight. b) Compensate the object's weight by merging it with another object that provides a lifting force (buoyancy), e.g. floating object or hot-air balloon. c) Compensate the object's weight by interaction with another medium, e.g. by means of aerodynamic or hydrodynamic forces. d) Use gravitational force or centrifugal force.	*Example 1: Car and truck spoilers are used as wings with a negative angle of attack to increase the road grip of the vehicle through the downward aerodynamic forces.* *Example 2: Hydrofoil boats. At high speeds the hydrodynamic lifting force of the underwater wings lifts the hull out of the water and it is then only supported on the foils.* *Example 3: A method for lifting sunken ships from the bottom of the ocean is to fill the cavities with a low density, water displacing medium such as, for example, plastic balls or fast-curing foam. The lifting force of this medium raises the ship to the surface.*
9	**Prior counteraction of harm**	a) If it is necessary to perform an action with both harmful and useful effects, counteraction measures against harm must be taken in advance. b) If the object will be under working stress, create beforehand stress in direction which is opposite the undesirable working stress. Thus, the working stress can be compensated. c) If the object will be exposed to high temperatures, cool it beforehand to avoid overheating. d) Use rigid constructions, highly stable structures (e.g. honeycomb) to withstand extreme operating conditions like high temperature, high pressure, high volume	*Example 1: To avoid vibrations during machining, the cutting tool is pre-stressed or preloaded to a value very close to the forces generated during the cutting process, so as to oppose them.* *Example 2: Pre-stressed structural steel elements. To reduce the bending of the structural steel elements under their own weight and the working load, the load-bearing profiles are pre-stressed and mounted so as to oppose the working load.*
10	**Prior useful action**	a) Perform the required action or useful function in advance, either fully or partially. b) Pre-arrange the objects so they can come into action at the most convenient position and without losing time. c) Perform a part of the process step or operation beforehand.	*Example 1: To increase the intensity of a gas flame, the gas is pre-heated to 600°-700°C before entering the burner.* *Example 2: To detect leakages of odourless and dangerous gases, a harmless but bad-smelling additive is introduced, which can be detected even in extremely low concentrations.*
11	**Preventative measure / Cushion in advance**	a) Compensate the low reliability of an object by preparing emergency countermeasures in advance. b) Increase process reliability by preparing emergency countermeasures in advance.	*Example 1: At speeds of over 65 mph, the risk of serious car accidents due to a tyre blow out is greatly increased. Fixing a steel disk behind each rim, which, in the case of a blow out, keeps the car in a level position, greatly reduces the risk of a serious accident.* *Example 2: Sleeping pills are covered with a thin film of an emetic substance. If more than the indicated number of pills is swallowed at one time, the concentration of the emetic substance reaches a threshold value in the stomach, which provokes vomiting.* *Example 3: To prevent frozen water from breaking its container, the inside of the container is lined with an expanded-cellular material, which, when the water freezes, is compressed by the ice.*

12	**Equipotentiality**	a) Change the working conditions so that an object doesn't have to be raised or lowered. b) Avoid changes of potential energy in the system. c) Avoid strong fluctuations of process parameter, peaks and valleys in energy consumption, thermal shocks etc.	*Example 1: The control system of a self-contained mobile robot (e.g. a moon Lander) guides it over the terrain avoiding obstacles like hills, rocks and crevasses by going around them instead of driving over them.* *Example 2: Changing the oil or other maintenance work on heavy vehicles is done in a pit under the vehicle, avoiding the need for expensive lifting equipment.*
13	**Inversion**	a) Instead of currently used action, carry out the inversed action with opposite direction or properties, e.g. heating instead of cooling, downwards instead upwards etc. b) Make a moving parts of the object fixed, and the fixed parts movable. c) Turn the object or process upside down. d) Perform the process or its phases in the reversed order. Change sequence of operations. e) Change properties or action mode of the external environment to the opposite: e.g. moving to fixed, high pressure to vacuum etc.	*Example 1: When cleaning parts with abrasive particles, vibrate the parts instead of the abrasive.* *Example 2: The computer mouse converts the movement of the ball on a static surface into a movement of the cursor on the computer screen. Because of the limited space in laptops, a trackball is used: here, the ball is movable but fixed in the casing, whilst the surface (hand) is movable.* *Example 3: The electric energy generated during the braking of electric machinery can be fed back into the mains supply.*
14	**Sphericity and Rotation**	a) Replace rectilinear parts or forms with curved, ball-shaped forms or structures. b) Use balls, rollers, spheres, domes or spirals. Apply cylindrical, conical or multi-conical configurations. c) Provide rotary motion of parts, substances or force fields. Replace a linear motion of objects or substances with rotation. d) Use vortex flows and swirling motion for cyclonic separation, cooling or heating. e) Use centrifugal and Coriolis forces.	*Example 1: A welding device for welding pipes onto the walls of a boiler uses ball or roller-shaped electrodes.* *Example 2: A space saving conveyor belt is in the form of a carousel.* *Example 3: To allow a vehicle to move in all directions, it's put on rollers instead of wheels.*
15	**Dynamism**	a) Make an object, external environment or process adjustable to enable optimal performance parameter at each stage of operation. b) Divide an object into elements whose position changes relative to one another. Make object movable and adaptive. c) If a process is rigid or inflexible, make it adaptive. d) Use adaptive and flexible elements like joints, springs, elastomers, fluids, gases, magnets/electromagnets. e) Change static force fields to movable or dynamics fields, which change in time or in structure.	*Example 1: The wing-shaped rear spoiler on a car is movable and automatically adjusts to the speed of the car. When an emergency stop is performed, the spoiler assumes a nearly vertical position to give maximum aerodynamic resistance and further increase the braking power.* *Example 2: The gripper of an industrial robot is made of several flexible spring steel fingers instead of rigid clamps, to automatically adjust to the shape of the object it has to handle.*
16	**Partial or excessive action**	a) If it is difficult to obtain exactly 100% of a desired effect, then obtain slightly more or slightly less. The problem may be considerably easier to solve. b) If it is difficult to obtain the optimal or exact amount of substance, apply an excessive amount. Remove surplus substance by using additional force or energy field. c) If it is difficult to obtain the optimal or exact action (force or energy field), apply an excessive action. Compensate surplus action by using protective shield.	*Example 1: To paint a cylinder completely, more than the required amount of paint is applied. Excess paint is then removed by rapidly spinning the cylinder.* *Example 2: To reduce the costs of plating a ship, instead of using very expensive steel plates cut to size using templates, uniform triangular, rectangular or hexagonal plates are used without having a negative effect upon the handling characteristics.*

17	**Shift to another dimension**	a) Change the straight line to a 2D or 3D curve, or plane form or movement to the three-dimensional. b) Reduce object size or dimensions to mini-, micro- or nano-level. c) Use a multi-layered or multi-storey structure of objects or processes. d) Tilt the object, lay it on its side, use reversed side or internal surfaces (hollows). e) Increase contact area between objects or substances from the contact along a line or on a surface to interaction in 3D-space.	*Example 1: To produce accurate cuts in fibre-reinforced materials, the teeth of the saw blades are arranged in two rows at different heights. Furthermore, the upper row of teeth has a different pitch to the lower one.* *Example 2: The effective area of a continuous loop (e.g. sanding belt or magnetic tape) is doubled if it is turned into a Mobius strip: the continuous loop is cut, one end is turned 180° and the ends are connected again.*
18	**Mechanical vibration**	a) Cause an object to oscillate or vibrate. b) If oscillation already exists, change, or increase its frequency (even up to the ultrasonic). c) Use the resonant frequency of an object and self-oscillations. d) Use piezo-electric vibrators instead of mechanical ones. e) Combine ultrasonic oscillations with other fields: ultrasonic and electromagnetic vibrations; ultrasonic with heat source; ultrasonic with capillary effect.	*Example 1: Apply an ultrasonic frequency to separate stuck parts simply.* *Example 2: Ultrasonic frequencies can accelerate chemical reactions and improve the transfer of heat to liquids.*
19	**Periodic action**	a) Replace a continuous action with a periodic or pulsed one. b) If an action is already periodic, change its frequency, amplitude, and mean value. c) Use pauses between impulses to perform additional actions. The frequencies of all periodic actions should be matched or intentionally mismatched. d) Avoid or use resonance. The frequencies of the periodic action should be matched or intentionally mismatched to the natural frequency of one of the objects. e) Apply mutually exclusive periodic actions alternately. Separate contradictory properties in time.	*Example 1: To intensify the heat exchange in a combustion chamber, the gas is applied in pulses.* *Example 2: If several programs are running simultaneously on a computer, the tasks with lower priority are executed between those with higher priority.*
20	**Continuity of useful action**	a) Carry on a process continuously (without pauses). b) All parts of an object or equipment should operate at full load. c) Eliminate all idle and intermittent actions or work.	*Example 1: A cutting tool which cuts in both forward and in reverse directions.* *Example 2: The electricity generated during the braking of electrically driven machinery can be fed back into the mains supply, instead of being converted into heat at the braking resistors.*
21	**Skipping / Rushing through**	a) Perform a process, or individual stages at very high speed to skip destructible or hazardous operations. b) Increase dramatically the speed or power in a process that may result in new useful properties of the system.	*Example 1: The critical operating conditions of a machine: the critical speed or resonant frequency is quickly passed through without damage being caused to the machine.* *Example 2: The cutting of flexible plastic parts is done at very high speeds. The cutting process is finished before the work piece deforms.* *Example 3: A phosphoric acid catalytic converter loses its useful properties at around 350°C, but is active again at temperatures exceeding 700°C. The hazardous region can only be skipped by rapidly heating the catalyst.* *Example 4: The rapid cooling of metal when casting or heat-treating increases its brittleness. If however, the metal is cooled very suddenly, a crystal latticework does not form, but instead, a very strong and useful material called metallic glass results.*

22	**Converting harm into benefit**	a) Utilize harmful factors or negative environmental effects to obtain a positive effect. b) Remove a harmful factor by combining it with another harmful factor. c) Amplify a harmful action to such a degree that it is no longer harmful.	*Example 1: Acidic and alkaline waste products from the chemical industry neutralize each other by simply being combined.* *Example 2: Use liquid nitrogen on frozen gravel or sand (over-freezing) to restore the material's ability to be spread.*
23	**Feedback and automation**	a) Introduce feedback to improve a process or action. b) If feedback already exists, change it: for example, its magnitude or influence. c) Increase a degree of automation and controllability of the system, use adaptive feedback control and artificial intelligence. d) Utilize information and data processing.	*Example 1: Industrial robots used for de-burring injection-moulded parts have an optical sensor to trace the contours of the part and guide the robot's arm or deburring tool.* *Example 2: For a faster and more exact machining of the contours of the work piece, the speed of the tool can be adjusted proportionally to the detected deviations from the desired values. This combination of sensor and speed control now forms a multiple feedback control circuit, and results in vastly improved efficiency.*
24	**Mediator**	a) Introduce an intermediate object to transfer or carry out an action. b) Merge one object temporarily with another intermediate object that can be easily removed. c) Use an intermediary process or process step.	*Example 1: For the non-destructive monitoring of the degree of setting of polymers, a magnetic powder is added to the substance. During setting, the changes in the permeability are measured.* *Example 2: For a loss-free supply of current in molten baths, easily removable metal electrodes with a higher melting point are used.* *Example 3: Urgent fault analysis and repairs in an airborne plane or spacecraft is done by experts on the ground using an exact copy.*
25	**Self-service / Use of resources**	a) Make the object serve itself and carry out supplementary and repair operations. b) Utilize waste resources, energy, or substances. c) Use available environmental resources: substances, energy, space, information, and data.	*Example 1: To investigate the effect of aggressive liquids upon different alloys, containers are made out of the alloys to be tested.* *Example 2: In electric welding, the welding-rod is usually fed through a special feeding device, in which one of the magnetic spools is controlled by the welding current.*
26	**Copying and modelling**	a) Use simple inexpensive copies instead of unavailable, expensive, fragile objects. b) Replace an object or process with its optical copies (graphical images, three-dimensional images, holograms). c) If visible optical copies are already used, move to infrared, ultraviolet, X-ray copies, optical or radio shadows. d) Use digital models and computer simulations. e) Use virtual reality, computer augmented reality etc.	*Example 1: To measure the accuracy of large cone-shaped castings, the cones are placed in a tub, which is slowly filled with water up to a particular height. The contours of the water levels are recorded by a camera and this data is used by a picture editing computer program to generate a three-dimensional model of the object.* *Example 2: The height of tall objects can be determined by measuring their shadows.* *Example 3: Thermal imaging using infrared cameras.*
27	**Disposability / Cheap short-living objects**	a) Use cheap short-living objects or substances. b) Replace an expensive object by a multiple inexpensive one, forgoing certain qualities (e.g. longevity). c) Use one-way disposable or temporary objects. d) Create cheap short-living objects from available resources, such as waste, water, air, environment etc.	*Example 1: Disposable products like paper towels, party sets, personal hygiene products, etc.* *Example 2: Plastically deformable metallic energy absorbers or shock absorbers such as those used for the landing of space probes.*

28	**Replacement of the mechanical working principle**	a) Replace the mechanical working principle by electric, magnetic, or electromagnetic one. b) Use optical working principle, for example IR, UV, Laser, LED. c) Use an acoustic or sound system, for example ultrasonic, infrasonic, etc. d) Use thermal, chemical, olfactory (smell) or biological system. e) Use electromagnetic fields in conjunction with ferromagnetic particles, magnetic or electro-rheological fluids.	*Example 1: As an additional warning mechanism for detecting leaks of odourless and/or dangerous gases, a harmless but bad-smelling additive is introduced which is detectable even in very low concentrations.* *Example 2: To increase the adhesive force and density of the layer of metal powder on a thermoplastic object, an electromagnetic field is applied during the coating process.* *Example 3: For the non-destructive monitoring of the degree of setting of polymers, a magnetic powder is added. During setting, the changes in permeability can be measured.*
29	**Pneumatic or hydraulic constructions**	a) Use gas or liquid as working elements, for example gas and liquid flows, aero- and hydrostatics or dynamics, hydro-reactive systems etc. b) Replace solid parts by gas or liquid, e.g. inflatable elements, air cushion, parts filled with liquids under pressure. c) Use negative pressure, partial vacuum, and vacuum chambers. d) Use fluidisation of powders, dusts or granulates in the air flow, for example in the fluidised bed. e) Use fluids and gases for heat and energy transfer: heat pipe, heat exchanger, vortex cooler tube, shock waves, cavitation etc.	*Example 1: A system of high-power fans can create an airflow that acts as an invisible roof, which can cover an area the size of a football-field shielding it from rain and snow.* *Example 2: Air-filled 'bubble-wrap' or other expanded-foam material stabilize and protect goods of any shape in a transport container during shipping.* *Example 3: Individuals suspected of having suffered spinal damage are transported to hospital on evacuated mattresses filled with small balls.*
30	**Flexible shells or thin films**	a) Replace traditional constructions with those made of flexible shells or thin films. b) Isolate the object or parts from its environment using flexible shells or thin films. c) Use piezoelectric foils. d) Apply flexible brushes for guiding, cleaning, vibration damping. e) Use membranes, membrane operations and processing.	*Example 1: The Harmonic Drive gear has a flexible toothed gear shell. Apart from having a very high gear ratio with only a single transmission, this solution also allows motion to be transmitted through a hermetic wall.* *Example 2: Gases can be separated using thin films, which allow some molecules to pass better than others. (US Pat. 4239506).* *Example 3: Piezoelectric foils made of e.g. polypropylene or polyester are used in acoustics (ultrasound-detectors, echo depth sounder, probes for medical echograms), as pressure transducers (acceleration meter, keyboards, non-destructive material testing, measuring the distribution of compression on surfaces) or as oscillators/vibrators (lightweight headsets, protection of ships' hulls against marine infestation).*
31	**Porous materials**	a) Make an object or its surface porous, or add porous elements (inserts, covers, etc.). Utilize objects with hollow spaces or cavities. b) If an object is already porous, fill the pores with a useful substance. c) Utilize capillary and micro-capillary effects in porous materials. d) Use the filler in combination with physical effects, e.g. ultrasound, electromagnetic field, temperature differences, osmosis etc. e) Use structured porosity, like honeycombed structure, pipes or canals, capillaries on the molecular level.	*Example 1: Using porous aluminium instead of the solid material brings a significant weight reduction and improves damping properties with a relatively high compression strength.* *Example 2: Some parts of an electric machine are constructed using porous material (or covered with a porous material), which is soaked in a liquid coolant. Should the machine overheat, the stored coolant evaporates, cooling it down rapidly and evenly without the need for an external cooling system.* *Example 3: A porous, heat resistant rod soaked with alloy additives, is used to add these substances to the casting.*

32	**Changing colour**	a) Change the colour of an object or its external environment. b) Change the degree of transparency of an object or its external environment. c) Use coloured additives to observe an object or process which is difficult to see. d) If such additives are already being used, add luminescent traces or other tracer elements.	*Example 1: To detect and locate very small leaks in cooling systems, a fluorescent substance is added to the coolant, which becomes visible under ultraviolet light.* *Example 2: A transparent bandage allows a wound to be inspected without removing the dressing.*
33	**Homogeneity**	a) Make objects interacting with a given object of the same material, or material with identical properties. b) The interacting objects should have similar properties such as size, weight, temperature, optical or magnetic properties etc. c) Homogeneous or uniform distribution of material or properties (temperature, concentration, viscosity etc.).	*Example 1: The cores of permanent casting moulds have almost the same coefficient of thermal expansion as the cast parts. This way, thermal stresses within the castings are avoided.* *Example 2: The glass and the foil of laminated glass sheets have the same optical refractive index.* *Example 3: The transport of small steel balls in a pipe entails an increased wear on the inside of the pipe bends. To minimize the wear, a layer of these balls, held in place by a permanent magnet, is positioned between the pipe wall and the flow of balls. By doing so, the flowing balls no longer collide with the pipe wall, but with the captive layer of balls.*
34	**Discarding and restoring**	a) Reject or modify (discard, dissolve, evaporate, etc.) a part of an object after it has completed its function or become useless. b) Restore any part of an object which has become exhausted or depleted directly in operation. c) Generate object or material just on time and on site, that can be more efficient and less expensive.	*Example 1: Instead of using sand to blast the surface of cavities, use the hard particles of frozen carbon dioxide (dry ice). After treatment, the particles evaporate without leaving any residue.* *Example 2: The wings of hydrofoil boats erode due to the cavitation-effect of the water. As a counter measure, the wings are frozen which generates a thin, protective layer of ice that is constantly renewed.*
35	**Transformation of the physical and chemical properties**	a) Change an object's aggregate state (e.g. solid to liquid or liquid to gas - or vice versa). b) Change the object's concentration or consistency. c) Change other relevant physical properties or operational conditions (pressure, density, hardness, viscosity, conductivity, magnetism etc.), separately or together. d) Change the object's temperature. e) Change other chemical properties or operational conditions (formulation, pH, solubility etc.), change process chemistry.	*Example 1: Gases are often stored and transported in liquid form, e.g. liquefied petroleum gas tanks, gas lighters etc.* *Example 2: Surfaces can be blasted with frozen drops of water instead of sand. The small drops of water are sprayed into a very low-temperature airflow, where they freeze.* *Example 3: For the mechanical processing of objects made out of flexible polymers (elastomers), they are frozen with liquid nitrogen, making them behave temporarily like a solid body.*
36	**Phase transitions**	a) Use phenomena accompanying the phase transitions of a substance, e.g. the emission or absorption of heat energy, density or volume changes, etc. b) Use the second-order phase transitions: shape memory of metals and polymers, transition beyond the Curie point in ferromagnetic substances, conversion of a crystalline structure etc.	*Example 1: To hermetically seal a joint of different cross-sectional areas, the section to be sealed is filled with a low melting-point metal. During its solidification, the metal expands and assures a hermetic seal.* *Example 2: Many mechanical constructions use the shape memory effect of metals – a property that some alloys (e.g. nickel titanium) possess. After deformation these alloys can return to their original shape when heated to a certain temperature: pipe connections, thermo-mechanical actuators, shock absorbers etc.*
37	**Thermal expansion and contraction**	a) Use thermal expansion or contraction of materials (solids, fluids or gases). b) Use constructions made of multiple materials with different coefficients of thermal expansion, e.g. bi-metals. c) Use heat shrinkable materials, e.g. heat shrinkable tubing. d) Use thermo-mechanical shape memory of metals and polymers.	*Example 1: The fine adjusting of the mechanical stage of a microscope can be performed by utilizing the controlled linear expansion of an electrically heated metal rod.* *Example 2: Bi-metallic plates made up of materials which have different coefficients of thermal expansion, are often used as thermo-mechanical actuators to open or close the windows of a greenhouse, for example.*

38	**Strong oxidants**	a) Replace common air with oxygen-enriched air. b) Replace oxygen-enriched air with pure oxygen. c) Expose air or oxygen to ionising radiation, use ionized oxygen. d) Raise the ozone level. Replace ozonized (or ionized) oxygen with ozone. e) Use other strong or extreme oxidants.	*Example 1: To combat airborne bacteria and viruses the air is enriched with ozone by using ultraviolet emitters.* *Example 2: To intensify the oxidation process in the production of ferrite coatings, the process is carried out in an ozone-rich atmosphere.*
39	**Inert environment**	a) Replace the normal environment with an inert one. b) Carry out the process in inert atmosphere of e.g. helium or argon. c) Carry out the process in a vacuum. d) Use inert, protective or antioxidant coatings or additives. e) e) Use foams or foamed substances to protect or isolate objects.	*Example 1: Due to the lack of oxygen in vacuum shrink packs, the storage time of food can be increased.* *Example 2: Covering the welding arc with an inert gas (argon) prevents oxidation of the weld.* *Example 3: As a preventive measure against fire, cotton is often shipped in an inert atmosphere.* *Example 4: A carbon dioxide fire extinguisher.*
40	**Composite materials**	a) Replace a homogeneous, uniform material with a composite one, e.g. carbon-fibre composite, laminates etc. b) Take advantage of the anisotropic properties of the composite materials, like mechanical, electrical, thermal. c) Use additives to provide specific properties to the composites, e.g. fire retardant additives in polymer matrix composites. d) Use materials with composite microstructure, controllable by external field. e) Use a composition of materials in different aggregate states, e.g. mixture of liquid and gas.	*Example 1: Carbon and glass fibres in reinforced plastics are so arranged that they optimise the mechanical properties of the parts.* *Example 2: Adhesives which contain carbon fibres, have a more crystalline structure and become conductive to electricity. The setting of the adhesives can be influenced through the application of an electric current.* *Example 3: The coolant used in heat treating processes is a gaseous and liquid mixture.* *Example 4: Aluminium foam sandwich as light-weight structural material.*