THE PSYCHOLOGY OF INVENTIVE CREATIVITY

G.S. Altshuller, R.B. Shapiro

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An investigation into the human psyche that improves the instruments of labor, has great significance for research and an understanding of the laws of technical creativity, which is the basis of technical progress.

Unfortunately, scholarship has thus far failed to address the evident rift between the enormous significance of technical creativity and the attention accorded it in the field of psychology. Suffice it to say that the only monograph on this issue in Soviet scholarship in psychology is P.M. Jacobson's book dating back to 1934, *The Process of the Creative Work of the Inventor* [7]. Despite the author's dubious initial assumption, due to the lack of any other studies, Jakobson's work has had, and continues to exert, a serious impact on how issues related to the psychology of technical creativity are presented in general psychology courses, monographs on the organization of the work of scientific workers, and, finally, in popular science literature.

The work is based on D. Rosman's formal chronological system for classifying the stages of the creative process [8].

Rather than exploring the internal laws of the creative work of the inventor, D. Rosman and P.M. Jakobson equated such different psychological processes as the stage of searching for a solution and the stage of designing the invention. This results from the fact that neither Rosman, nor Jacobson uncovered the special features of technical creativity in general, and inventive creativity in particular. The fundamental issues of the psychology of inventive creativity remained unresolved, and, rather than studying them, the authors based their research on such general scientific matters as "insight," "breakthrough," "guessing," "conception," "gestation," etc. The corresponding sections of the monograph by K.G. Vobliy, *The Organization of the Work of the Scientist*, were written from the very same false stance. According to Vobliy, "*In the initial stage of the creative process one can distinguish between the stages of preparation, gestation, ripening, and breakthrough. In the daily train of thoughts, these stages often overlap*." [2; 123-124] Of interest is that this "analysis" is by no means a step forward in comparison with T Ribot's statement made more than 50 years ago: "*When this hidden work has been fulfilled to a sufficient degree, the idea behind a solution suddenly appears, resulting from a willful mental tension or a certain cerebral observation, as if a veil has been lifted, behind which was hidden the image of the proposed solution*." [5; 228]

These views are based on the theory of "constructive intelligence" advanced by A. Ban, which reduces the entire panoply of processes related to technical creativity to a "mental experiment," which follows the "rule of trial and error." The influence of this theory was manifested even in such a seminal work as S.L. Rubenstein's *Foundations of General Psychology*: "*When the point* *that requires rationalization, change, the introduction of something new, is found, noted, realized and, as it were, planted in the mind of the inventor, a certain process begins in which a wide variety of observations and all kinds of knowledge that enters his mind are concentrated and tied to this point: All these observations and facts are as if applied to the central point and correlated with the problem occupying the mind of the inventor, and at times a lot of the most unexpected associations sometimes are made in his head*."[6; 576]

At the same time, for the first time, Rubinstein correctly noted the characteristic features of inventive creativity: "*The specificity of the invention, distinguishing it from other forms of creative intellectual activity, is that it must create something, an actual object, mechanism, or technique that solves a certain problem. This is what determines the originality of the inventor's creative work: the inventor must introduce something new in the context of reality, in the actual course of some kind of activity. This is something that differs significantly from solving a theoretical problem, in which a limited number of abstract conditions must be considered. At the same time, reality is historically mediated by human activity and technology: embodied in it is the historical development of scientific thought. Therefore, in the process of inventing, one must proceed from the context of a reality which requires the introduction of something new, considering the corresponding scientific context. This determines the general direction and specific character of the various elements in the process of inventing.*" [6; 575].

However, this process is not entirely accurate. Take, for example, the architect, who has to create a "real object," introduce something new "into the context of reality" and consider the "relevant scientific context".

Because of this inaccuracy, a very fruitful and valuable thought actually slipped by without notice: In the textbook widely used in schools, thus far they speak only about creativity "in general".

The psychology of creativity is one of the most least developed branches of psychology.

Creativity is a complex process, the laws of which are diverse and elusive. But the specific nature of inventive creativity to a certain extent simplifies the task of the researcher. The results of creativity in art depend not only on objective reality, which reflects the work of art, but also on the author's world view, on his aesthetic ideals, and on many even random factors. Inventive creativity is connected with a shift in technology that develops in accordance with certain laws. The process of creating a new instrument of labor, regardless of the state of mind pertaining to it, is subject to objective laws. Its reflection in art, generally speaking, can largely separate it from reality (for example, in fairy tales, legends, myths). Whatever the technical problem is, it cannot be solved unless it complies with the laws of science and depends on the laws of technological development.

Research on the psychology of inventive creativity cannot be conducted in isolation from research on the basic laws of technological developments. The inventor's activity is aimed at creating new technological objects, because the inventor is a participant in technological progress. Therefore, the psychology of inventive creativity becomes clear only with a deep knowledge of the laws of technological developments. This, of course, does not mean that the researcher should be engaged only in studying the mechanism of technological progress. The unique nature of the psychology of inventive creativity as a scientific discipline consists of the need to simultaneously consider the objective laws of technological development and subjective, psychological factors. The psychology of inventive creativity first and foremost pertains to the field of psychology. Therefore, the focus is the mental activity of the inventor, the person improving and adding to the technology. The psychology of inventive creativity acts as a bridge between the subjective world of the human psyche and the objective world of technology, and therefore, regarding research on inventive creativity, it must consider the laws of technological development.

There are two sides to the inventive process: materially substantive and psychological. To identify the materially substantive aspect of an invention, we need to know the history of technological development, as well as understand the basic laws of technological progress. The study of materials on the history of technology, an analysis of specific inventions are one of the most important sources to a psychology of technical creativity.

To identify the psychological patterns of the inventive process, we must systematically observe the process of the creative work carried out by inventors, generalize the experience of innovators, and experimentally study the process of inventive creativity by conducting experiments in conditions as close as possible to the real world.

Work in this direction has been underway since 1948. Numerous materials on the history of technology, and extensive memoirs related to the work of major inventors have been studied. Descriptions of inventions in the Code of Inventions of the Soviet Union, as well as patent literature from abroad, have been systematically examined. We devoted special attention to summarizing the experience of innovators from the foremost enterprises of Soviet industry. We also used the results of our own observations on the creative work carried out by the inventors and efficiency experts in Azerbaijan's petroleum industry. Our findings were subjected to practical tests at two machine-building plants, at the Vano Sturua cracking plant and at the *Leninneft N8* oil-field operations.

In order to truly understand our findings, we must be familiar with the basic laws of technological development. These laws are complex and diverse. Since these laws are outside the scope of this article, we shall limit ourselves to information required for an understanding of the essence of the creative process.

In *Capital*, Karl Marx provided the structural and functional characteristic of a machine:

> "*All fully developed machinery consists of three essentially different parts, the motor mechanism, the transmitting mechanism, and finally the tool or working machine. The motor mechanism is that which puts the whole in motion. It either generates its own motive power, like the steam-engine, the caloric engine, the electromagnetic machine, etc., or it receives its impulse from some already existing natural force, like the water-wheel from a head of water, the wind-mill from wind, etc. The transmitting mechanism, composed of fly-wheels, shafting, toothed wheels, pullies, straps, ropes, bands, pinions, and gearing of the most varied kinds, regulates the motion, changes its form where necessary, as for instance, from linear to circular, and divides and distributes it among the working machines. These two first parts of the whole mechanism are there, solely for putting the working machines in motion, by means of which motion the subject of labor is seized upon and modified as desired*."
> [Translation from *Capital*, 1; Chapter 15, pp 378-379. Translated by Samuel Moore and Edward Aveling, Progress Publishers, Moscow, USSR]

There is a definite correlation between the main components of the machine the working body, the transmission mechanism (transmission) and the engine, because all these parts are in a close relationship and interact with each other. Biologists have long known a law that Darwin called the law of the ratio of growth: a change in the individual parts of an organic being is always associated with a change in its other parts. This law is an isolated instance of the well-known position from the Marxist dialectic about the universal interconnection of phenomena. The interdependence of individual components of a machine in the process of its development is another isolated instance in the general law of dialectics.

The fact that there is a relationship between the main components of the machine leads to the fact that the development of one or another part is possible only to a certain limit – until there is a contradiction between the modified part of the machine and the remaining unchanged other parts. For example, even a simple "*increase in the size of the machine, and in the number of its working tools, calls for a more massive mechanism to drive it… In the 17th century attempts had already been made to turn two pairs of millstones with a single water-wheel. But the increased size of the gearing was too much for the water power, which had now become insufficient...* " [1; 382-383] The contradictions that have arisen between the individual parts of the machine act as a brake on overall development, because further improvement to the machine is impossible without making changes to its relevant parts, without a radical improvement in their properties.

Let us consider the basic facts of the history of the bicycle. In 1813, the Austrian forester Drais built a “running machine” – the prototype of a modern bicycle. In Western Europe, the self-propelled carriages designed by the remarkable Russian mechanics L. Shamshurenkov and I.N. Kulibin were not known, and the first bicycles created by Drais lacked something that the carriages of the Russian inventors had: a transmission: you had to push it along with your feet. Without a transmission, a subsequent improvement in the working bodies (wheels) and controls made no sense, and so the bicycle turned out to be a fun toy, but not a means of transportation. Only when pedals mounted on the axle of the front wheel were introduced were there any new opportunities to improve the bicycle. The pedals let riders increase how fast they could go, but with an increase in speed, operating the bicycle became more dangerous, as the controls were inadequate. The invention of brakes (1845) addressed this issue: it was possible to further develop the working body, increasing the diameter of the drive wheel and thereby increasing the distance traveled on the bike with one revolution of the pedals. The diameter of the front wheel increased from year to year: So-called ‘spider bikes’ were created featuring a huge front wheel. Finally, the quantitative path of development exhausted the options: a further increase in the diameter of the front wheel dramatically increased the dangers inherent in cycling. The resulting contradiction was eliminated by changing the transmission by means of a chain transmission, which made it possible to reach a high speed not due to the large diameter of the wheel, rather due to an increase in the number of revolutions. An upgrade in the transmission again paved the way for a development of the tools: In 1890, pneumatics were introduced. The resulting increase in the speed of bicycles led to a new change in the transmission: the use of a free wheel mechanism. That’s how the modern bicycle was created.

Even a cursory outline of its development allows us to draw the following conclusions:

1. The individual elements of the machine, mechanism, process are always in a close relationship.
2. Developments take place by fits and starts: some elements outstrip others in their development, while other developments lag behind.
3. The orderly development of a system (machine, mechanism, process) is possible until the contradictions between the more advanced element and its less advanced parts are manifested and become more acute.
4. This contradiction act as a brake on the overall development of the entire system. The elimination of the contradiction is an invention.

5. A fundamental change in one part of the system necessitates a number of functionally conditioned changes in other parts.

Consequently, every creative solution to a new technical problem — no matter to which field of technology it belongs — includes three main items:

1. The formulation of the problem and the determination of the contradiction standing in the way of the solution to the problem using standard, already well-known technological methods.
2. The elimination of the causes of the contradiction aimed at achieving a new, higher technical effect.
3. Bringing the other elements of the improved system in line with the upgraded element (the system is given a new form corresponding to the new entity).

Along with this, the process of creatively solving a new technological problem usually includes three stages that are different in purpose and method that we conditionally call ***analytical***, ***operational***, and ***synthetic***.

The analytical stage aims at analyzing the development of a given machine, mechanism, process (or, more generally, a branch of technology) to identify the main contradiction at this stage and determine the direct (physical, chemical, etc.) causes of this contradiction. The operational stage is a systematic and expedient, focused study of possible ways to eliminate the cause of the contradiction that has been identified. The synthetic stage is directed at introducing additional changes to the other elements of the system resulting from the method that has been found to eliminate the technical contradiction.

The inventor’s creative work begins in the first phase of the analytical stage, i.e. when the problem is selected. Rubinstein’s opinion that the inventor must develop a tendency to look closely at what “can be changed, redone, improved” is completely erroneous. It is possible to change and improve all tools and equipment without exception; there is nothing that can't be changed. The goal of the inventor isn’t in the mechanical choice of whatever matter he happened to take a look at, but in the creative study of the dynamics of the development of a certain system and in identifying what problem is decisive at this stage, what is it that acts as a brake on overall development.

This is especially typical of Soviet inventiveness, which is associated with planned production. Modern production, especially specialized, is comprised of a series of consistent, interrelated processes. An enterprise’s total production capacity is usually limited by one of these processes which acts as a bottleneck for production as a whole. When inventors haphazardly do everything that “can be changed, overhauled, improved,” in some parts of the production process an excess in production capacity is created, and this remains untapped because of the “bottleneck” inhibiting overall development.

Of considerable interest is the experience of the inventors and efficiency experts of the *Baku Metal Oil Storage Vessel Plant*. The production process at this plant requires that all of the workshops be coordinated in their operations. Initially, streamlining production was carried out here by each innovator at his production site. At the same time, despite the large number of introduced innovations, the total production capacity at the plant saw virtually no increase. For example, the innovators from the welding department made significant improvements to the design of the automatic welding machines. This allowed a speed increase in the welding process. When the machine was working, a more products were produced per unit of time. And yet in tandem with this, machine downtime increased because the productivity of the preparatory department remained the same. In this regard, at the beginning of 1948, a systematic survey of the plant was conducted to identify "bottlenecks" that hindered improvements to production as a whole. This made it possible to identify and formulate the most urgent problems requiring an orderly, consistent solution, at which, subsequently, the entire team of inventors and efficiency experts would direct its efforts. As a result, between 1948 and 1955, labor productivity at the plant saw an eight-fold increase.

The second phase of the analytical stage is identifying the main element in a problem. When solving each specific technological problem, one must choose what characteristic (element), what change is both necessary and enough to achieve the desired technical effect in the machine, mechanism, or process.

A classic example of how to correctly identify the main component in a problem is provided by the famous English inventor James Watt in his work creating a better version of the steam engine. Having set for himself the goal of creating such a machine, Watt analyzed in detail all of the characteristics of the steam engines existing at that time. These engines had a number of significant drawbacks: the bulkiness and explosiveness of the boiler plant, the huge heat losses in the cylinder of the engine, flaws in the transmission. Watt correctly identified the main element in the problem: reducing heat losses in the cylinder of the engine and, therefore, increasing the overall efficiency of the machine as a whole. Watt's improvements to this characteristic allowed the creation of a steam engine of a sufficiently high power. Subsequently, Watt set for himself a new challenge: to make the steam engine universal. The power of the cutting-edge steam engine fully met the requirements of the day. And so, the main element now was improving the transmission, which was adapted to generate only infrequently used in and out movements. By changing this basic aspect of the problem, creating a transmission capable of generating a circular motion, Watt succeeding in creating a universal engine.

The selection of a problem and the definition of its main element is only the first half of the analytical stage of the creative process. When an attempt is made to solve a problem with already known technical means, contradictions arise that impede the attainment of the desired technical effect. The identification of a crucial contradiction is the third phase of the analytical stage.

For example, an attempt to increase the efficiency of a boiler plant by introducing additional screens and economizers weighs down the unit and increases the amount of metal required in the construction. As we attempt to improve one of the issues using conventional methods, we simultaneously worsen the others: "*To some extent, the desire to reduce the weight (economize on metal) and the desire to increase efficiency (economize on fuel) contradict each other. The resolution of this contradiction is one of the most important factors in the progressive development of boiler equipment ...*" [4; 146]

This contradiction, obviously, is a consequence of defined causes. The problem in the last – fourth – phase of the analytical stage of the creative process is determining the immediate (mechanical, chemical, etc.) causes of the contradiction. Let us provide an example. The last stage in the prefabrication of dial gauges is that of checking them by comparing them with a verified reference sample. The instruments are placed side by side, and the controller checks the readings at several points on the scale. It is obvious that in order to increase the accuracy of the controls, one must take the greatest possible number of control points, but this slows down the verification process, leading to a decrease in the controller's labor productivity. In our effort to gain in accuracy, we undergo a loss in the speed of the verification process. The direct cause of the contradiction is the physical impossibility of combining the scales in the two instruments: the controller has to look from one device to another, and he needs to see both at the same time. In this case, the contradiction is eliminated by introducing a binocular system that optically combines the instrument dials, making it possible to quickly and accurately verify the coincidence of the readings of both instruments throughout the entire scale.

The analytical stage is the most "logistical" part of the creative process. With an experienced inventor it represents a logical sequence of judgments, the catalyst to which are historical, statistical, technical, economic and other facts. And only in rare cases, when at some stage there is not enough factual material, we must conduct a few, always targeted experiments.

That being said, the analytical stage is an extremely important part of the creative process. In many cases, a properly conducted analysis allows one to immediately eliminate the cause of a technical contradiction or to greatly facilitate the next — operational — stage of the creative process.

What determines the success of creative work at the analytical stage? A background in the relevant technological field, an understanding of the dialectic laws for its development, having all of the factual information necessary for an analysis and the ability to conduct a logical analysis. It follows that **to develop one's inventive abilities, one must constantly train one's analytical skills**. Before he starts operating on living people, the surgeon spends a long time working with cadavers. Similarly, the inventor must systematically study already existing inventions. Also of great importance is a background in the history of technology, and an ability to imagine changes and developments in each branch of technology. Finally, the actual totality of technical knowledge, the totality of actual material that is available, is also important.

The second part of the creative process – the operational stage – differs in many ways from the first. In most cases, the operational stage is a combination of logical and non-logical operations. In this regard, the inventor has to search, try, or, using an old and not quite accurate term, conduct a "**thought experiment**," which – this must be emphasized – takes precedence only at the operational stage of creativity. And the main thing is that it should not be carried out haphazardly. If the "thought experiment" was "a process of trying to and incorporating in this point all kinds of information" (S. L. Rubinstein), then the creative solution to each technological problem would require many years. Each more or less experienced inventor systematically carries out work on the operational stage of the creative process. As a result of long practice, inventors gradually develop their own, often rather unconscious, but objectively rational system for conducting searches. The analytical stage of the creative process greatly simplifies these searches: the inventor is not looking for an abstract "idea," rather he seeks out concrete ways of eliminating a specific technical contradiction.

In our opinion, the most rational is a system in which the search for a way to eliminate the cause of a technical contradiction is conducted in the following sequence:

1. Researching typical solutions (prototypes):
   a) The use of naturally occurring prototypes,
   b) the use of prototypes from other areas of technology.

2. Seeking out new solutions through changes:
   a) within the system,
   b) in the external environment,
   c) in adjacent systems.

With this sequence, searches go from simple to complex, and so we generate solid solutions with minimal effort and time.

In many cases, the technical contradictions that we encounter while carrying out creative work have direct analogies in nature and technology. Therefore, it is advisable that the first step we take is an investigation of similar contradictions and typical ways to eliminate them. Often, this lets us use natural or technical prototypes to eliminate the cause of the technical contradiction.

Let us provide an example. During WWI, ships began to use hydrophones – instruments that would detect the noise made by submarine propellers. To use these hydrophones, the ship had to be stationary, or the speed had to be seriously cut: the sounds made by the ship's movement through the water at the receiving hole of the hydrophone drowned out everything else. One of the engineers who worked on improving the hydrophone knew that seals could hear perfectly even as they sped through the depths of the ocean. At the suggestion of this engineer, a hydrophone was built with a receiving hole that was similar in shape to a seal's auricle. The result was a massive improvement in the capacity of the hydrophone to detect sound even when the ship was moving through the water.

In 1933, a device was invented in the USSR to drop cargo from a plane without a parachute (*Author's Certificate No. 41356*, published in the USSR). When solving a problem, the inventor used the well-known property of maple seeds, which, when they fall, level out and slowly gyrate toward the ground. He built a device that reproduces the maple seed's shape and so, when dropped from an airplane, gradually descended, spinning around its center of gravity.

A typical example of the use of technological prototypes is provided by the work of the designer E.V. Kostychenko (machine-building plant), who focused on the problem of increasing the wear resistance of valves used in deep-well pumps. Submersible pumps for extracting oil from wells quickly fail because the valves are abraded by the sand contained in the oil. Attempts to increase the service life of valves using hard alloys did not meet with success: they managed to increase the endurance of the valves, but along with this, the valves were much more difficult to process and manufacture, and they were also much costlier. To eliminate this contradiction, Kostychenko employed a technique that is widely used in mechanical engineering. Self-sharpening cutters, wherein the outer layers are made of soft metal, had been used for some time in metal processing. During the work process, these layers are uniformly ground, while the overall shape of the cutting edge is maintained. By using soft metal to cover some of the valve parts, the inventor succeeded in ensuring that they wore down evenly, and so the valve shape was maintained even when 9/10ths of the parts were worn out. Currently, over 100,000 pumps at use in oil fields are equipped with Kostychenko's valves.

The use of natural or technical prototypes is not, of course, limited to simple copying. Natural and technological prototypes are the result of long, ongoing development. When deriving a solution from nature and technology, the inventor develops it, bringing it to a logical finish.

In cases where a study of natural and technological prototypes does not produce a positive result, the inventor then proceeds to the next phase of the operational stage – a search for new solutions Along with this, potential changes to the system itself are investigated. This is the usual group of the simplest changes. In some cases, to eliminate the cause of the technical contradiction, all we have to do is change the dimensions, materials, and the sequence in which the individual parts of the system interact. A typical example is the creation of a cutting machine with a long bar. The standard bar used to cut into a coal vein is 2 m long. In this process, explosives are used to crush the coal. Under favorable geological and geological conditions, it is possible to use cutting-edge machines with a 3-5 m bar. By increasing the depth of the cut, the coal is crushed by the movement of the coal cutter: as it settles, the coal is broken into large, transportable pieces. A quantitative change – an increase in the length of the bar – thus provides us with a new qualitative effect: it eliminates the need for drilling and blasting operations.

A significant group is comprised of changes in the external environment. When studying the feasibility of making changes, the inventor must study the external – for the system – environment and its impact on the system. In particular, consideration should be given to changing the parameters of the medium (for example, pressure, temperature, speed of movement) or replacing this medium with another that has more favorable characteristics. Often, a simple transition from one environment to another, or the introduction of additional components into the environment leads to a successful solution to the problem. For example, in the manufacture of concrete in conventional concrete mixers, in a concrete mass, even with prolonged mixing, a significant number of small air bubbles remain, and these reduce the concrete's strength. Therefore, the so-called vacuum method for preparing the concrete was proposed. In vacuum concrete mixers, the concrete mass is mixed in a rarefied medium created inside a drum. A quantitative change in one of the parameters (pressure) of the environment provided a new qualitative effect: the strength of the concrete was doubled.

A technical contradiction can also be eliminated by amending adjacent systems, adjacent machine parts, and other stages of the process. Sometimes, all one needs is to simply establish a relationship between previously independent processes. We know, for example, that direct current is used for lighting modern film studios. This is called for by the fact that the shooting speed (24 frames every 2 seconds) does not match the frequency of the alternating current used in industry (50 Hz). When using alternating current to power lamps, the shutter of the lens on the movie camera may open when there isn't much light, and so some frames will be too dark. The shutter speed for each frame as it is shot is usually 1/1000s, so only 2.4% of the light energy falling on the lens is useful. If the fast-response lamps are powered by current pulses, synchronous and common-mode rotation of the lens shutter, the light will turn on only when the lens is open. Artists will see a significantly weaker uninterrupted light, since even at 10-16 pulses per second the human eye perceives light flow as continuous. By establishing the relationship between how the camera and the lighting system operate, we get a new technical effect – a sharp reduction in power consumption which also makes the work of artists easier.

The analytical stage of the creative process almost always results in an unambiguous answer, which is in contrast to the operational stage: A single technical contradiction can be resolved in various ways. Therefore, at the operational stage, an experiment doesn't play a secondary role, rather, the main one. This is because, in many cases, it serves as the criterion for the final choice of a particular technique, method, approach, etc.

A solid background in the natural sciences, the ability to observe, a familiarity with related areas of technology, an understanding of the technology involved in the experiment – these are the qualities necessary for success at the operational stage of the creative process.

The last – synthetic – stage of the creative process encompasses four stages: The introduction of functionally determined changes to the system, the introduction of functionally determined changes to the methods of applying the system, testing the applicability of the resulting principle in solving other technical problems and assessing the invention. Like the analytical stage, the synthetic stage is primarily comprised of a chain of logical judgments that, if necessary, can be verified through experiments.

The method employed to eliminate technical contradictions almost always requires additional changes to the system. These changes are aimed at providing a new form to the system that corresponds to the new content. Psychologically, the transition to a new form presents the inventor with considerable difficulties. This is due to the fact that each system (machine, mechanism, process) involves presenting people with old, well-established forms. Because of this, even when a system is fundamentally changed, the inventor often retains its “traditional” form. Thus, for example, an early version of the electric motor was designed to look a lot like a steam engine: instead of a cylinder, the motor employed an electromagnetic coil, and a metal rod replaced the piston, which used reciprocating motion to switch the current. As was the case with the evolution of steam engines, a crank-and-rod mechanism was used to transform this motion into a rotational movement. Only later were rotating motors used in electric engines, thereby eliminating the need for a crank mechanism.

The next phase of the synthetic stage of the creative process is the introduction of changes to the methods used to apply the system. Creating any new system (or changing from a previous system) requires finding new methods for its practical use. Here’s a classic example. Previously, coal miners extracted coal manually, using pick axes. Periodically, they would stop the extraction process, and set up fortifications and goafing. In the early 1930s, they started using pneumatic jackhammers in the mines, which was a powerful tool for breaking up the coal. However, the way the work was carried out didn’t change in that periodically, the miner still put down the hammer to work on fortifications. Because of these irrational working methods, there wasn't much improvement in overall production. Then a new method was proposed for organizing operations: one group of miners would keep on breaking up the coal with jackhammers, while another group worked on fortifications. This new approach made it possible to take full advantage of the jackhammers, resulting in a tenfold increase in coal production.

Despite the obvious importance of this stage of creative work, inventors often largely overlook it, as efficiency experts use empirical methods to employ new inventions. As in the previous stage of the creative process, this is due to the influence on the inventor’s mindset of established, traditional work methods.

The third phase of the synthetic stage of the creative process is verifying how applicable the new method is in eliminating technical contradictions for solving technical problems. Sometimes the resulting principle behind the invention is even more valuable than the actual invention itself, and can be successfully applied to other, more important problems. At this stage, the inventor’s technical prowess, his acquaintance with other technological realms, his knowledge of current issues prevalent in various industries are of particular importance.

Everybody knows that in 1867, a French gardener by the name of Monier secured the first patent for reinforced concrete. Monier lacked a strong technical background, and so his patent application was only for manufacturing reinforced concrete ... flowerpots.

The last stage of creative work is the assessment of the new invention. At this stage, the goal is to identify the relationship between the technological benefit of the invention and the costs of its implementation. The value of the invention is directly dependent on how great this relationship is. In particular, if there are several solutions found at the operational stage, the final selection of the best option is made in conjunction with an assessment of the invention. Also, at this stage, inventors usually analyze the work done thus far in an attempt to identify any flaws and to fully work out new creative approaches to solving the problem.

The general course of the creative process is illustrated by the following example. In 1949, the USSR Ministry of Coal Industry announced an all-Union competition for the creation of a refrigeration suit for mining rescue workers, who encounter high temperatures and a poisonous atmosphere in their work. The technical conditions of the competition indicated the key to the task, that being the need to ensure long-term refrigeration in a light-weight suit (8-10 kg). This is because, in their work, the mining rescue workers had to carry a device for respiratory protection (12-14 kg), as well as tools, and the total permissible load for each person couldn’t exceed 28-29 kg.

The work on creating the refrigeration suit was launched by the authors of this article with their identification of the main technical contradiction. It was as follows. To ensure that the suit would hold up for a sufficient length of time in terms of its protective qualities, the supply of refrigerant (ice, dry ice, Freon, etc.) had to be increased, and, consequently, the weight of the suit also had to be increased. Any attempt to reduce the weight of the suit would inevitably reduce the service life of the suit, as well. Thus, there was a contradiction between the two main characteristics (weight and service life) that could not be eliminated by standard engineering. The analysis of this contradiction showed that the primary factor was the low weight limit established by the conditions of the competition.

While exploring how to eliminate these contradictions, we found that in other branches of technology this is often achieved by the so-called “method of combining functions”: the functions of one system are added to this system, and by their elimination [from the first system] we now create the option of increasing the weight of the first system. In this case, the solution to the problem was achieved by transferring to the refrigeration suit the functions of the apparatus for respiratory protection. As a result, the total allowable weight of the combined suit could be increased to 20-22 kg. Such a formulation of the question predetermined the choice of refrigerant: It had to be oxygen stored in a liquefied state. The undergarment worn inside the suit was first cooled by evaporated oxygen, which then was used for breathing once it heated up.

At the synthetic stage, changes based on function were made to the system: Due to the large supply of oxygen, instead of a circular (regenerative) breathing system, an open system was used (with exhalation into the atmosphere), which made it possible to dramatically simplify the design of the respiratory functions of the suit. We also made changes to the way the suit was used, as well. Since the suit rapidly becomes lighter as it is used thanks to the evaporation of oxygen, it was now possible to first load the suit with extra liquid oxygen, thereby increasing the suit’s service life.

Projects based on these principles were awarded both the first and second prizes by the judges at the competition [3].

Based on all of the above, the creative process can be schematically laid out as follows:

I. Analytical stage

1. Selecting a problem.
2. Defining the key to the problem.
3. Identifying the key contradiction.
4. Determining the immediate cause of the contradiction.

II. Operational stage

1. Researching typical solutions (prototypes): a) in nature, b) in the technology.
2. Seeking out new solutions through changes: a) within the system, b) in the external environment, c) in adjacent systems.

III. Synthetic stage

1. Introducing functional changes to the system.

2. Introducing functional changes to the system based on changes to how the system is used.
3. Testing how applicable the principle is to solving other technological problems.
4. Evaluating the resulting invention.

Of import is that the scheme we are planning can be attributed only to the creative work of an experienced and highly skilled inventor. As regards the work of a novice inventor, as a rule, there is not enough logical judicial symmetry, and chance, and lucky finds, and such play an important role. That being said, the great inventors of the past often achieved a high level of creative skill.

Inventions can be made in the process of carrying out research. For example, the discovery of X-rays and the establishment of their properties almost automatically led to a number of technological inventions based on the use of these rays. In this case, the inventor first acquired a means of eliminating many technical contradictions, and the problem was the opposite: find these contradictions.

The scheme we set forth is typical, but not comprehensive. Moreover, even within the limits of applicability, it is approximate. In many regards, one must still refine, deepen, and to some extent modify this scheme.

To solve this problem, one must further study the relationship between the objective laws of technological progress and the mental processes of technological creativity. One must also systematically study the experience of efficiency experts and inventors, and identify and study general methods of creative work.

The formation of the psychology of inventive creativity as a branch of psychology is impossible without the wide application of the experimental method. The findings should be verified not only by referring to materials related to previous inventions, but also experimentally, because the ultimate goal of the psychology of inventive creativity is the practice: Known patterns should be used in the development of scientific methods of work on the invention.

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