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Material Science – Mathematics and Mathematical Physics in Alloys and Other Materials for Foundry

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Abstract
This article examines the methodology and philosophy of complete knowledge in terms of: history of science and the individual sciences from antiquity to the present; fundamental results and their applications; development guidelines. This approach is applied when considering the historical development from metal science to material science with all the knowledge known today. In the technological revolution 4.0, material science is also the subject of a knowledge transfer industry.

Keywords: Methodology and philosophy of science, metal science, material science, technology revolution

1. Introduction – methodology [1-8] and philosophy of the science

The term philosophy is from Greek *φιλοσοφια* it means: *φιλεῖν* – love and *σοφία* – wisdom. The system of principles of philosophy are in constant evolution and change to respond to the intense dynamics of reality. The definition is [1]:

Philosophy is the study of general and fundamental questions concerning man and the world, with mine areas and objects research. (PHILOSOPHY)

On the table 1 are:

Table 1. Fundamentals of philosophy

METAPHYSIC	Nature and origin of the existing and the world
ONTOLOGY	Being
EPISTEMOLOGY	Knowledge of nature and possibility of cognitive process
ETHICS	Morality how to act human, correct behavior and „good live"
POLITICAL PHYLOSOPHY	Governance and respect for human and communities to the state
AESTHETICS	Beautiful, sublime, art, pleasure
LOGIC	(mathematical and Philosophical) – Forms and lows of thinking
PHILOSOPHY OF LANGUAGE	Beginning, development, use and attitudes towards of thinking
SCIENTIFIC METHODOLOGY	(academic disciplines) – Grounds and subject science; history; mathematics; physics; psychology; anthropology; etc.

Philosophy [1] – in its earliest years, philosophy encompasses empirical knowledge and their description in the then accumulated knowledge. Knowledge is accumulated in the various fields of philosophy and explanations and logical connections are sought in each of them. Philosophy also separates the individual sciences, and the first separates mathematics, after that separates physics, etc. [1]. Philosophy of science has its historical roots in the history of science, methodology of science, scientific methods of research [2, 3, 4 and 5]. The history of science is closely linked to the history of philosophy, because science is separated from the latter [2]. The philosophy of science deals with all hypotheses, foundations, methods, results and the use of science and the use and contribution of science [3]. The philosophy of science is an old discipline used by Plato and Aristotle; on the nature of science, its knowledge and methods, and today on rational life and industrial progress [4]. The history of philosophy of science also has a strong educational significance [5].

The demarcation line in the philosophy of knowledge is "science/pseudo-science", but often "wrong demarcation lines" are introduced. For example (rationality/intuition): in [6] consider the phenomenology of the theory of strong interactions, quantum chromodynamics (QCD) of Standard Model processes in the experiments of the Large Hadron Collider LHC CERN. Theoretical calculations for predictions in the theory of disturbances for observations of large quantities of highly interacting particles, quarks, and gluons are presented. Such calculations form the most important class of correction for solving New Physics at LHC.

Heuristics means the approach to solving scientific problems when there are no other (tried and tested) ways or means to solve them [7]. Heuristics is something like the anti-thesis of standard thinking and there is no sharp line between non-heuristic and heuristic thinking; there is a connection and transition between these two approaches. Heuristics have a connection with the problem of artificial intelligence. The most **complete heuristic methods** are presented – Tong [7]: 1. Breaking down the problem of "small" parts with a goal and sub-goal organization of behavior; 2. Using behavioral indicators to identify among a large number of alternatives valuable to the program; 3. Use of recursive procedures so that sub-problems are solved with the same set of lumps as the problem itself; 4. Absence of a guarantee for obtaining a satisfactory solution, and often a decision at all. **Heuristic rules**, general approach of successive phases – Code [7]: 1. *Preparatory*, explaining the history of the problem, its formulation and the means available for its study; 2. Study phase covering analysis and synthesis, possibly reformulation, new analysis and synthesis (which may be repeated several times). A significant factor here is the time to be reckoned with; 3. The final phase, which consists of proposing a decision or decisions.

The term "methodology" is related to a whole group of concepts [8]: *theory of science*, *logic of science*, *philosophy* respectively *theory of knowledge*, *philosophy of science*, *heuristics* and so on. Relations between logic (L), methodology (M) and philosophy of science (P): independent concepts ($\neq$); matching ($\equiv$) or roughly matching ($\approx$); two cases of inclusion ($\supset$, $\subset$); excision ($\cap$) or union ($\cup$) i. e. that is, algebraic relations between fuzzy sets. If we take the concept of methodology as a starting point, we may have the following relationships: the methodology covers or partially covers philosophy; the methodology covers heuristics; methodology comes down to the logic of science.

In [9] presents a discussion of the concept of "**complicated**" from the perspective of Quantum Mechanics-*Complexity*-Biology. It is suggested that the language of quantum mechanics is probably useful or very essential at the cellular level, but it is not known how to apply it.

Work [10] is an essay with a response from the authors on "The theory of everything?". Work [10] is an essay with a response from the authors on "the theory of everything". Gerard'T Hoof (Utrecht University, Netherlands, 1999 Nobel Laureate): The most striking difficulty is the reconciliation of general theory of relativity with quantum mechanics; Leonard Susskind (Stanford University, CA, USA): The more you learn about cosmology and string theory, the less likely it is that string theory will describe our world; Eduard Witten (Institute for Advanced Research, Princeton, NJ, USA): Physicist theorists seem to find what looks like a unified field theory, but it continually puzzles them; Masataka Fukugita (Space Beam Institute, Tokyo University, Tokyo, Japan): Cosmology does not make much of a contribution to building a theory of everything; Lisa Randall(Harvard University, Cambridge, MA, USA): I believe that we will continue to make greater progress towards understanding fundamental laws of nature; Lee Smolin (Perimeter Institute, Waterloo, Ontario, Canada): One next step: finding a common source for the geometry of space-time and quantum phenomena, so that they can really be combined; John Stachel (Faculty of Physics, Boston University, Boston, MA, USA): Attempts to create a quantum theory of gravity run into the following problem: do we have to give up background independence to quantize gravity?; Carlo Rovelli (Center for Theoretical Physics, University of Marseille, Marseille, France): The big theoretical question is how to formulate quantum field theory so that it is consistent with what we have learned from general relativity, namely background independence; George Ellis (Faculty of Mathematics at the University of Cape Town, South Africa): The ultimate goal of the quest for "force and particle theory" is to unambiguously formulate a fundamental theory without any free parameters in it; Steven Weinberg (Faculty of Physics, University of Texas at Austin, Texas, USA. Nobel Laureate, 1979): The term "theory of everything" implies that there is some theory that will solve all scientific problems, there is no such thing. But there may be a "definitive" theory that will lead us as far as we can; Roger Penrose (Institute of Mathematics, University of Oxford, Oxford, UK): However, there is at least one significant gap in modern physical theory.

In an essay [11], the author considers the origin of Europe and culture as a region/continent "geographically" and Hellenic civilization with its identity cultural identity as a science, a philosophy at the heart of European civilization. The second part of the essay „Esprit de géométrie“ i. e. especially based on the science of Geometry. For us, another essential part of European civilization is Roman civilization. Judeo-Christian culture must be added here. Geometry or mathematics is an *essential* part of science.

For a complex process, we use the W. Corfield model [12]. It is known that quantum mechanics was created to describe the properties of metals, which are the largest part of the periodic system of chemical elements of Mendeleev. In [13], in addition to the Kossel–Stranski–Volmer–Kaishev theory, quantum mechanics is also presented. In [14] is the theory of solid state physics. These two books [13 and 14] are an important part of the history of not only metal science but also material science.

It has long been known that the sciences interact [7, 8], but one generalized approach to description is the synergetic that H. Haken calls a simple union of sciences [15]. Mathematics plays a huge role in science. It is well known that a field of knowledge becomes a science if and only when mathematics is applied. The first science to be separated from philosophy is mathematics. In [16] is presents the history of mathematics. Math does not need experiments. The math just expands and nothing falls away from it. The history of mathematics [16] shows its extension and the capabilities of the human mind.

Metal science [17] and solid state physics [18] are methodologically completely overlapped. The fundamental solidification results [19] are also methodologically overlaid with the engineering solutions in [21]. Metal science [17] methodologically overlaps with the curing processes [19]. Then, in our opinion, there is a common methodological scientific field [17, 18, 19 and 21] is the area of physical metallurgy [20] that is, following [7 and 8] it is the methodological field [17, 18, 19 and 21] is subdomain of [20] or *[17, 18, 19 and 21]* $\subset$ *[20]*.

Work [22] is a technological realization of the bulk and surface formation of non-ferrous and ferrous metal castings based on theoretical and experimental studies of the gas counter-pressure casting method. The methodology of technological solutions of the basic casting and heat treatment processes in [22] covers technological solutions except for metals as well as for ceramic materials and plastics, i. e. for material science. Therefore we have

[17, 18, 19, 21 and 22] $\subset$ [20]. **(A)**

A. Balevski's definition of the working properties of alloys (material) is the basic [17]:

Such a combination of mechanical and technological (and in some cases physical and chemical) properties that no pure metal possesses no matter what mechanical and thermal treatment it is subjected to. (Working Properties Material)

The working properties of each article include: the working properties of the material and the working properties of the macro-volume with its geometric complexity. Following the methodological (A) definition is obtained for the working properties of the product – cast:

Such a combination of mechanical and technological (and in some cases physical and chemical) properties that no pure metal casting possesses, no matter what mechanical and thermal treatment it undergoes. (Working Properties Cast)

The fundamental sciences are formed historically first – mathematics, physics, chemistry, biology, history, economics, etc., and are called monodisciplinary sciences – a set of objects and methods of research. The **object** (the source of the problem) is located in one, and the **methodology** (approaches, principles, etc.) is in the other (s). Their borders usually coincide with those of the united sciences, and their development goes in the same basic sciences. *Scientific development* in the 20th century has removed the boundaries between the various sciences and in the 21st, this tendency is: the separation of integrative sciences – **interdisciplinary** and classified according to the source of ***interdisciplinarity***: 1. *Interdisciplinary* sciences with *a source an central concept* defining the subject (problematic) is generally located in a very wide range of fundamental sciences and their methodologies. Interdisciplinary Science with a Central Concept of Self-Organization is Synergetics:

Synergy is a relationship in which the effect obtained is different or greater than the sum of the individual effects. Origin of the Greek word συνέργια meaning "work together".

Characteristic of synergetic is: it arises from physics (nonequilibrium thermodynamics, nonlinear processes, collective phenomena in many-particle systems – lasers, superconductivity, etc.). It quickly covers areas with processes of spontaneous structure formation – from chemical batch reactions, crystallization, etc.; 2. Another type of source of interdisciplinary is the central issue – *interdisciplinary sciences with a source of central issue defining the interdisciplinary situation*.

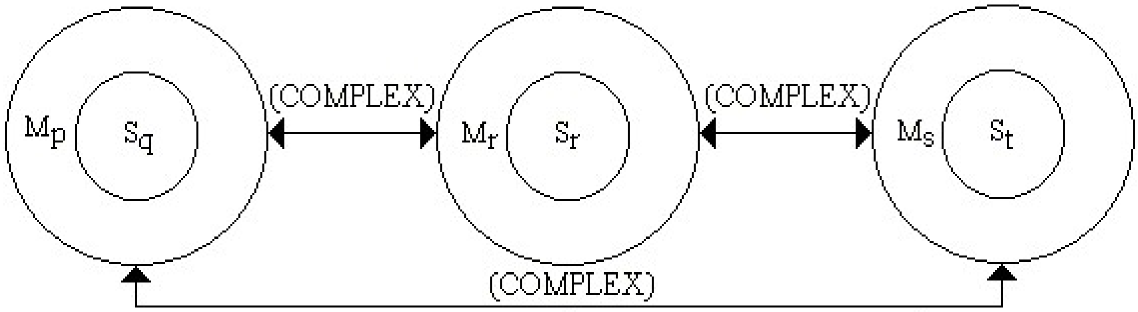
Examples of central issues are global problems (environment, greenhouse effect, ozone hole, population explosion, energy and raw materials, population nutrition, etc.).

Examples of global research problems that determine the interdisciplinary situation: the Large Hadron Collider, the Fusion Reactor, the Neutrino Experiment, Space Research, the development of global science and technology projects, and more. The implementation of these projects requires large budgets, the cooperation of huge teams of specialists from different fields.

Due to their huge scope, integrative sciences lead to a natural unification of knowledge – natural, technical and social sciences.

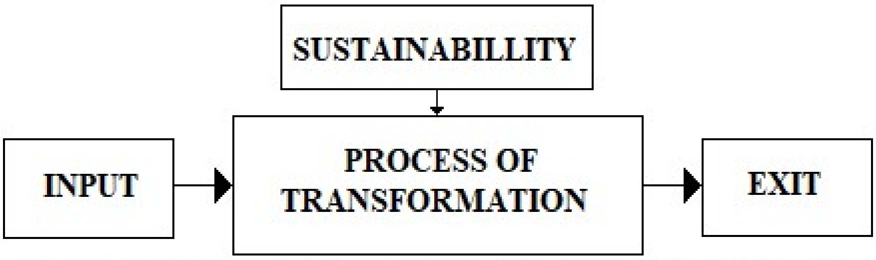
Central Concepts of Interdisciplinary Sciences – Chaos (C) and Order (O) [23, 28 and 29]: The concepts of chaos (C) and order (O) in these sciences place a dual (dichotomous) character – thesis and antithesis. Examples: simplicity and complexity, symmetry and antisymmetry.

SCIENCE AND METHODOLOGY



(1) The W. Corfield model of complexity of six phases: - 1chaos $\xrightarrow{+}$ 2complexity $\xrightarrow{+}$ 3unforeseen complexity $\xrightarrow{+}$ 4situational or contextual (portable) realization $\xrightarrow{+}$ 5diffusion (diffusion) and acceptance $\xrightarrow{+}$ 6unpredictability uncertainty 1chaos;

(2) Interdisciplinary approach (required sciences) + experiment to evaluate the impact and synthesis (unbundling) of an open system;



(3) An open system becomes technological if and only when its controllability is described, i.e. its stochastic behavior.

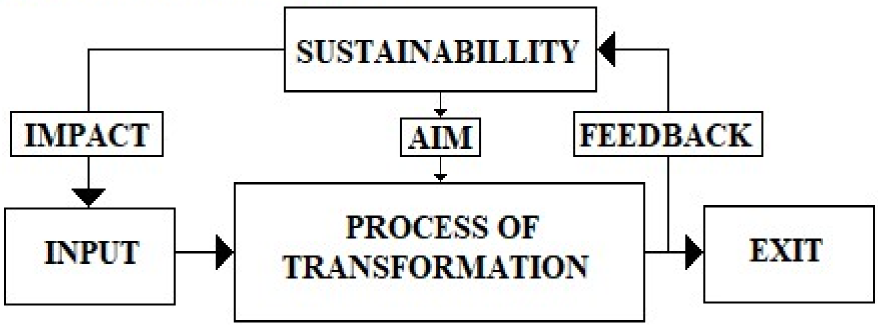


Fig. 1. Science and methodology – general scheme of [7 and 8] on the dependence of one science on factors: one examines the science of S_r with two other sciences S_q and S_t, and their methodologies M_r, M_p and M_s; Definition of complexity using the W. Corfield model [12]; Interdisciplinarity [15, 28, 29, 30, 31 and 32] Synthesis of Open Systems and an Open Technology System [28].

The chaos of physics came with the concept of "gas" by Van Helmon in the 17th century. Chaos and order as thesis and antithesis enters physics with the ideas of entropy (R. Clausius, 1865). Entropy is a quantitative measure of chaos in a system. For this reason, entropy quantifies chaos and joy. Symmetry describes the order in a system, the more ordered a system is, the lower its symmetry. At the end of the 20th century, physics distinguished several types of chaos [23]: 1. Non-deterministic chaos (NDC) – complex and random behavior in systems of many elements. It is due to random external or internal factors. A quantitative measure of this kind of chaos is entropy; 2. Deterministic chaos (DC) – irregular behavior of dynamic systems having the properties of a random process. It is due to a strong sensitivity to the initial conditions. For example, the random number generator; 3. Deterministic causes (O) and consequences (O) are associated with order; with chaos – random causes (C) and consequences (C). Deterministic causes give rise to deterministic or random consequences. Accidental causes give rise to deterministic causes or accidental consequences. The O→C transition is described by the (interdisciplinary!) Theory of deterministic chaos. The C→O transition is described by the interdisciplinary science of synergetic or the theory of dissipative structures. The four types of transitions are:

Order → Order; Order → Chaos; Chaos → Chaos; Chaos → Order. **(B)**

An important feature of the interdisciplinary sciences is that they generate new connections in the field of knowledge.

The development of integrative sciences of great, even critical importance, is the role of scientific schools, which always grow thanks to leading figures. Such examples from Bulgaria are: N. Obreshkov – Mathematics; I. Stransky – R. Kaishev – Physic chemistry; L. Krastanov – meteorology; A. Balevski – I. Dimov – metal science, counter pressure casting; I. Kostov – crystallography; I. Todorov – theoretical physics. The great difficulty is in integrating integrative sciences into existing scientific knowledge.

In [27 and 28], a scientific methodology was established for the two main processes of material science: **foundry** and **heat treatment** and shows on Fig. 1

It can be said that the development is from metal science to material science. The first-order phase transition in the foundry and the second-order phase transition in the heat treatment require their full description i.e. full knowledge of material science. The reasons are: 1. These processes are essential for obtaining macro- and micro-structures, carriers of working properties and require a multi-scale description approach; 2. Another reason for stepping outside the field of metal science is that all possible materials are already cast: metals, alloys, glasses, plastics and composites are easy to create.

The aim of this article is the need for material science and working with full modern knowledge.

2. Historical development from metal science to material science and full known knowledge

We present the science used in our institute through the classification and historical approach presented in the following two periods:

Algorithm Classification "POLICAR" – Historical Approach
Institute of Metal Science and Metal Technology – Bulgarian Academy of Sciences

Angel BALEVSKI, Ivan DIMOV

Scientific foundations	Physics of metals	Physics-chemistry	Phase transitions	Metal science	Physics Solid Body	Experiments	Balevski – Dimov – Nedyalkov Mathematical modelling

Technological research

Counter-pressure casting. Species	Metallurgy under Pressure	Heat treatment	Welding	Plastic deformation	Electro-Magnetic Studies
Analyzes and structural investigations of metals and alloys					
PATENTS					
INNOVATION					

Applied research

Machine building	Transport: Road; Rail-road; Air Transport.	Space	Energy	Special applications

Institute of Metal Science, Equipment and Technologies With Center of Hydro-and Aerodynamics – Varna "Acad. Angel Balevski" – Bulgarian Academy of Sciences

Stefan VODENICHAROV

Physics of metals	Physics-chemistry	Phase transitions	Metal science	Physics Solid Body	Experiment	Daskalov; distribution on sciences sections Mathematical modelling	Hydro- Aero-dynamics
Counter-pressure casting. Species	Metallurgy under Pressure	Heat treatment	Welding	Plastic deformation	Electro-Magnetic Studies	Analyzes; Structures	Hydro-aerodynamic technologies
Thin layers and technologies				Special investigation, alloys, materials and technologies			
PATENTS							
INNOVATION							

Applied research

Machine building	Transport: Road; Rail-road; Air Transport.	Space	Energy	Special applications

The history of scientific, technological development and economic realization can be summarized as follows:

INTERDISCIPLINARY SCIENTIFIC FOUNDATION – MATERIAL SCIENCE

Mathematics	Theoretical Physics	Physics Solid Body	Chemistry	Applied Mathematics	Hydro-Aerodynamics	Physical and technological experiments.

Important conclusion: the scientific classification, it is clear to us that an implicit transition is made **metal science → material science** naturally through the applications based on the **first-order and second-order phase transitions**. The scientific foundation is the full knowledge.

3. Material Science, Technological revolution

The history of mathematics at the institute is mathematical modeling. The Institute was invited by the Institute of Nuclear Research and Nuclear Energy Prof. I. Nedialkov, Head of the Section "Mathematical Modeling in Physics and Engineering". Mathematical modeling topics were managed by A. Balevski, I. Dimov and I. Nedyalkov. In the next historical stage the Department of Mathematical Modeling in Physics and Engineering was headed by K. Daskalov. There is a huge hunger for mathematics at the institute and for this reason the members of this scientific section have been distributed to different scientific departments.

Why should mathematics be developed at our institute? Because the development of material science is based on complete knowledge: **mathematics; crystallization, nucleation theory, mathematical physics; theoretical physics; chemistry, quantum mechanics, quantum physics**.

In [27] outlines the fundamental idea of the Industrial Revolution 4.0 – Knowledge transfer in the economic. This requires a new competitive environment – a knowledge economy. If knowledge is a subject of commerce, then the work of specialists must first know it in detail and secondly know where to apply it. The only science that doesn't need experiments and is only expanding is mathematics. In the field of material science, the needs are full knowledge, i. e. first of all mathematics with mathematical physics and theoretical physics.

It is well known that there is no universal mathematics and one must always keep in mind Gödel's theorems. It is therefore always necessary to: observe: the demarcation line science / pseudoscience; the boundaries between the interacting sciences are blurred, the interaction between methodologies every science; continuous lifelong learning; very dynamic programs in education from child to scientist.

Demarcation Line required: (Fundamental Research/Applied Research) is identical to (Fundamental Research/Knowledge Transfer in Industry 4.0). Fundamental research is with possible result. An example of "theory of everything": there is hope, but work continues, despite the great difficulties, etc. Industrial Research: Fundamental knowledge is known – the physical experiment confirms the theoretical result. Industrial research is already the subject of company institutes and high-tech companies. An set of (sciences with their methodologies, {(S_q, M_p), (S_r, M_r), (S_t, M_s)}) interact through (heuristics, complexity, interdisciplinary, multiscale) seems like this (see Fig.1):

$$\{S_q; M_p\} \xleftrightarrow{COMPLEX} \{S_r; M_r\} \xleftrightarrow{COMPLEX} \{S_t; M_s\} \xleftrightarrow{COMPLEX} \{S_q; M_p\}. \qquad \textbf{(C)}$$

The relations (A), (B), (C) with (Heuristics (rules, methods), complexity, interdisciplinary, multiscale) for us are a generalized idea of interaction at dynamics at different speeds in 3D (X, Y, Z, t) space-time i. e. hierarchy with respect to the three axes in time. The relations (A), (B), (C) with (Heuristics (rules, methods), complexity, interdisciplinary, multiscale) for us are a generalized idea of interaction at dynamics at different speeds in 3D (X, Y, Z, t) space-time i. e. arrangement between close currents with respect to the three axes in time. On the based work [27] of Fig. 2, we present a general scheme of an office for knowledge transfer

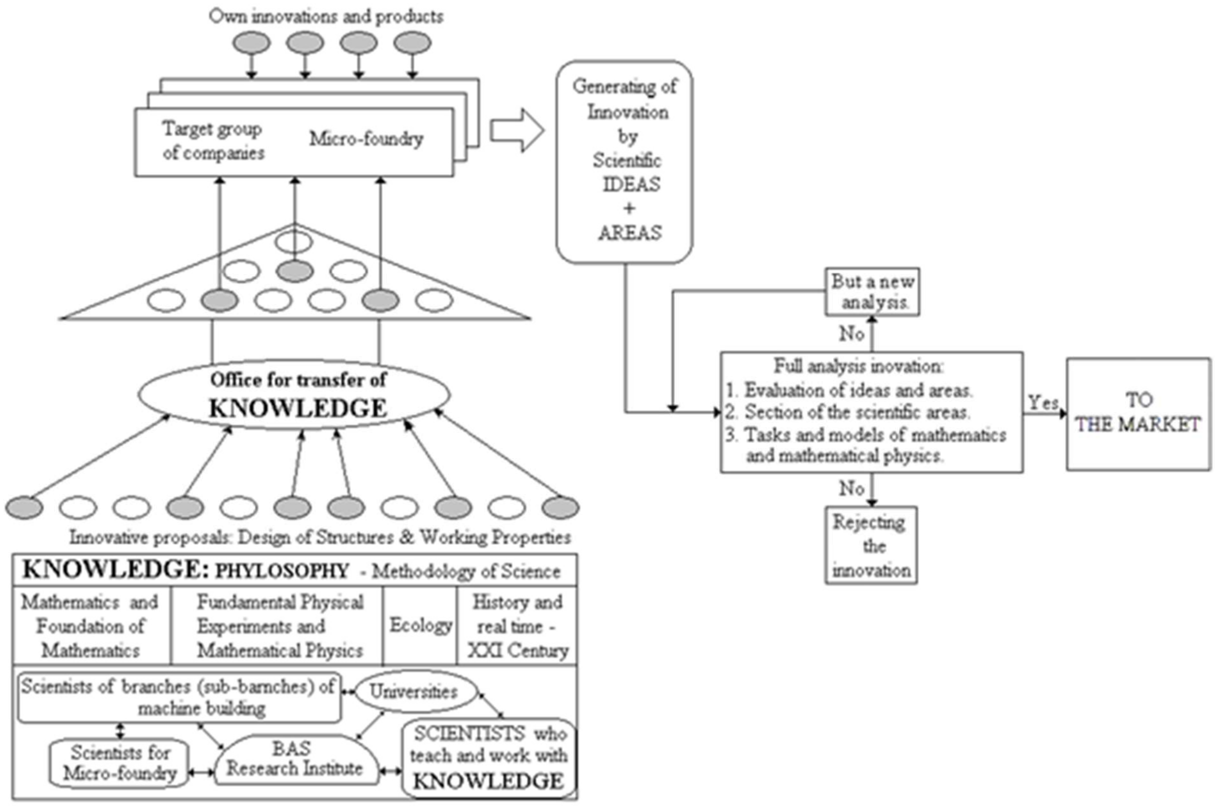


Fig. 2. Knowledge transfer office for Micro-foundry assistance. Design of products and micro-structures of material. Scientific services are obtained from a higher level: for example, from a branch organization and membership fees. Full knowledge Wites and innovation ideas + areas of our transfer are the grays; Full analysis of generated innovation.

4. Conclusion

„Mathematical Modeling in Physics and Engineering“ to be changed to „Mathematics in Physics and Material Science“, which is a job for a sub-institute for the purpose of: covering the whole subject of the institute. Example: Many materials are cast at the Institute: alloys, ceramics, plastics and composites, which requires *MATERIAL SCIENCE* with it's the sciences based: {Mathematic}; {Metal science [17], Theory of solid body [18]}; {Theory of crystallization [24], Nucleation [25], Crystal growth and epitaxy [26]}; {Solidification [19], First-order phase transition in casting [32]}; {Software for calculating the properties of materials from first principles. [33]}.

The main proposal is to create an economy-wide Knowledge Transfer Industry (ITS) (**Fig.3**) and the Bulgarian Academy of Sciences (BAS) expertly works and studies the fundamental knowledge of the world.

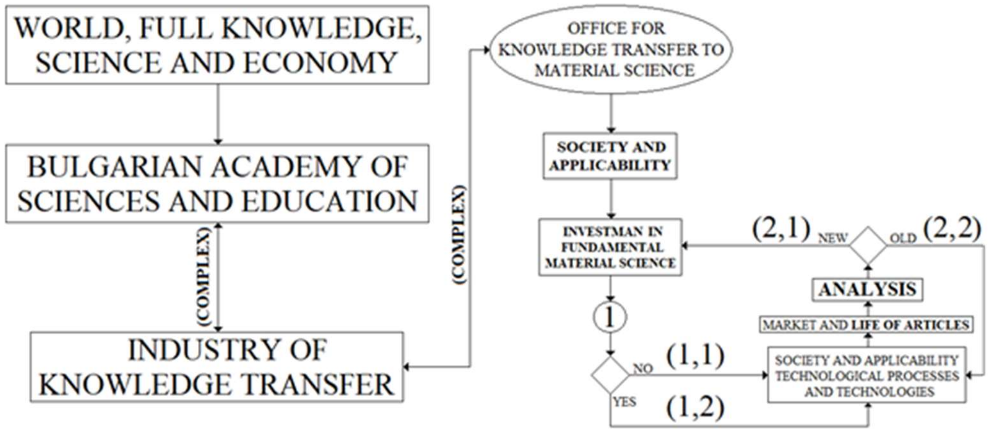


Fig. 3. Knowledge transfer for MATERIAL SCIENCE in Industry 4.0.

Material science in Industry 4.0 requires much more basic knowledge than the sciences cited above, because in describing the properties of modern materials, new ideas and new interactions of sciences are required; development of mathematics and physic.
Institute to become a Center for Materials Science: Institute of *Materials Science*, Equipment and Technology with the Hydro and Aerodynamic Center "Acad. A. Balevski "at the Bulgarian Academy of Sciences. The interaction of BAS with ITZ is most effective.
The knowledge transfer industry is high-tech with offices throughout the economy; interacts with the Bulgarian Academy of Sciences and with large high-tech companies.

References

1. https://bg.wikipedia.org/wiki/Философия; https://bg.wikipedia.org/wiki/
2. A. Rosenberg, Philosophy of science, Routledge Taylor & Frances Group, New York and London, 2005. ISBN 0-203-08706-2
3. https://web.stanford.edu/class/symsys130/Philosophy%20of%20science.pdf
4. The Blackwell Guide to the Philosophy of Science, P. Machamer and Michael Silberstein, Blackwell Publishers Inc., 2002. ISBN 0-631-22107-7
5. B. Ellis, R. Home, D. Oldroyd, R. Nola, H. Sankey, K. Hutchison, N. Thomason, J. Wilkins, J. Forge, P. Catton, and R. Barton, https://www.researchgate.net/.../278702723_History_and_Philosophy_of_Science
6. M. A. Lim, Thesis of PhD, Quantum chromodynamics and the precision phenomenology of heavy quarks, University of Cambridge, 2018.
7. A. Polikarov, Methodology of scientific knowledge, Science and Art, Sofia, 1972. (In Bulgarian)
8. A. Polikarov, Essays on Methodology of Science, Science and Art, Sofia, 1981. (In Bulgarian)
9. R. Rosen, H. H. Pattee, R. L. Somorjai, A Question of Physics: Conversations in Physics and Biology, Routledge & Kegan Paul, London and Henley, London, 1979. ISBN07100 03I3 7
10. F. Tampoia, The Origin of Europe and the esprit de geometrie https://philpapers.org/rec/TAMTOO-3
11. Gerard'T Hooft; Leonard Susskind; Eduard Witten; Masataka Fukugita; Lisa Randall; Lee Smolin; John Stachel; Carlo Rovelli; George Ellis; Steven Weinberg; Roger Penrose; A

theory of everything? In. NATURE. 2005; Vol. 433, No. 7023. pp. 257-259. Translation by M. Bushev, World of Physics – 4, 2005, pages 391-399. (In Bulgarian)
12. W. Corfield, PhD. Thesis, Queensland University of Technology Brisbane, Australia, 2006.
13. G. Schulze, Physics of metals, Peace, Moscow, 1971, (In Russian)
14. J. Blakemore, Solid state physics, Metallurgy, Moscow, 1972. (In Russian)
15. G. Gaglioti and H. Haken, Proc. of the International School of Physics □□Enrico Fermi, Sinergetitics and Dynamic Instabilities, 24 June – 4 July, 1986.
16. U. C. Merzbach and Carl B. Boyer, A History of Mathematics, Third Edition, John Wiley & Sons, Inc., ISBN 978 0 470 52548 7
17. Balevski A., Metalscience, Technics, Sofia, 1962. (In Bulgarian)
18. M. Borisov, K. Marinova, Introduction of physics of the solid body part I, Science and Art, Sofia, 1977. (In Bulgarian)
19. M. Flemings, Solidification Processing, Peace, Moscow, 1977. (In Russian)
20. R. E. Smallman, R. J. Bishop, Modern Physical Metallurgy and Materials Engineering, sixth edition, Butterworth-Heinemann, Oxford, 1999. ISBN 0 7506 4564 4
21. J. Campbell, Castings Practice: The 10 Rules of Castings, Butterworth-Heinemann, Oxford, 2004. ISBN 07506 4791 4
22. Y. Arsov, E. Momchilov, K. Daskalov, G. Bachvarov, Theoretical and technological fundamentals of gas counter-pressure casting, Academic publishing house, Sofia, 2007. ISBN 978-954-322-199-8
23. M. Bushev, The world of physics, 2/2010, 220-227. (In Bulgarian)
24. R. Kaishev, Selected Works, “Prof. Marin Drinov”, BAS, Sofia, 1980. (In Bulgarian)
25. D. Kashchiev, Nucleation: Basic Theory with Applications, Butterworth-Heinemann, Oxford, 2000. ISBN 0750646829
26. I. Markov, Crystal Growth for Beginners: Fundamentals of Nucleation, Crystal Growth, and Epitaxy, 2nd Edition, World Scientific Publishing Co. Pte. Ltd., New Jersey, London, Singapore, Hon Kong, 2004. ISBN 981-238-245-3
27. S. Bushev, Knowledge transfer Industry 4, International Scientific Journal, „INDUSTRY 4.0“, Yare I, ISSUE 1 / 2016, 51-54. ISSN 2543-8582
28. S. Bushev, These of PhD, Controllability problems of crystallization process in casting, TU – Sofia, 1993.
29. S. Bushev, G. Moumdjian, A possibility to influence the dynamics of a phase transition of first order during casting in open thermodynamic systems, Comptes rendus de l’Académie bulgare des Sciences, Tome 46, No 7, p.27-30, 1993.
30. St. Bushev, Modelling and Numerical Estimates for Phase Transitions in Metal Alloys, Institute of Metal Science, Equipment and Technologies With Hydro- and Aerodynamics Center „Acad. Angel Balevski“ at the Bulgarian academy of sciences, Sofia 1574, 67 „Shipchenski prohod“ blvd. Bulgaria, 2011.
31. St. Bushev, Modeling and Prediction of Phase Transitions in Metal Alloys, Institute of Metal Science, Equipment and Technologies With Hydro- and Aerodynamics Center „Acad. Angel Balevski“ at the Bulgarian academy of sciences, Sofia 1574, 67 „Shipchenski prohod“ blvd. Bulgaria, 2014.
32. S. Bushev, Theoretical model of structure formation in die casting, XXII International scientific technical conference „FOUNDRY 2015“, 16-17 April 2015 Pleven, Bulgaria (In Bulgarian)
33. CASTEP, www.tcm.phy.cam.ac.uk/castep/oxford/castep.pdf