Open Journal of Philosophy, 2024, 14, 448-480
https://www.scirp.org/journal/ojpp
ISSN Online: 2163-9442
ISSN Print: 2163-9434

Philosophically Specified Types of Methods Important for Theoretical Natural Science*

Jaroslav Kubrycht

Department of Physiology, Second Faculty of Medicine, Charles University, Prague, Czech Republic
Email: jkub@post.cz

How to cite this paper: Kubrycht, J. (2024). Philosophically Specified Types of Methods Important for Theoretical Natural Science. *Open Journal of Philosophy, 14,* 448-480.
https://doi.org/10.4236/ojpp.2024.142029

Received: April 8, 2024
Accepted: May 20, 2024
Published: May 23, 2024

Abstract

In accordance with current philosophical opinions, four classical and one more recently proposed types of methods frequently used in theoretical natural science are specified here together with the corresponding sources of inspiration. More precisely, abstract models, thought experiments, mathematical hypotheses and metaphors are dealt with here as classical types of methods, whereas hybrids of mathematical hypotheses and thought experiments represent more recent methodic group. In addition, this paper describes the relationships of the introduced types of methods to the (i) three-floor hierarchy of scientific theories, (ii) examples of ancient or recent discoveries and (iii) recent usage of computers.

Keywords

Model (s), Hypothesis, Metaphor, Theoretical, Thought Experiment (s)

1. Introduction

Four types of frequently used theoretical methods (TTM) can be denoted as classical TTM, i.e. as many centuries used groups or families if not categories of methods. Three of TTM represent important synthetic forms of ideas, i.e. **abstract models** (**AM**), **thought experiments** (**TE**) and **mathematical hypotheses** (**MH**) (Černík et al., 1980; Ado et al., 1981). In addition, intuitionists add to the centre of theoretical investigations **metaphors** (**Mp**), used elsewhere but exhibiting considerable importance in theoretical science (Stachová, 1993). **Hybrids of MH and TE** (**HMT**) then represent more recent TTM (Míček, 1981).

The aim of this paper consists in contribution to better and more frequent usage and creation of TTM. This could to be important, because progress usually

*Types of theoretical methods in natural science.

occurs when genius attempts like many well-known TTM become the school routine. In addition, the knowledge about TTM can sometimes help us to clarify trends in theoretical and empirical science, our own considerations or important points of school lectures. I show here the corresponding definitions or specifying notes, various subset classifications, ways of origin, multiple important structural features (chapters 2-4), some sources of the corresponding inspiration (chapter 7), relationships to computers (chapters 5 and 8), hierarchy of theories (chapter 6) as well as TTM interrelationships (chapters 2-4 and 10). In addition to examples from history (chapter 8), I deal with here the result of the first historical reconstruction performed in case of TE (Černík, 1972; Míček, 1981; chapter 2) and proposed also by another scientist (Ernst, 2015). Though the specific methodological natural-science-related approaches described here differ from related general informatics-based classification of theoretical science expressed in two papers (Nilsen, 2015; Bergeron et al., 2017), the author of the first of these papers consider importance of epistemological view in his Conclusions, i.e. view specifically discussed here.

2. Thought Experiment as a Half-Brother of Laboratory Experiment and Sci-Fi

According to **historical reconstruction** (Černík, 1972; Míček, 1981) of thought experiment (TE) development, TE arose in Antique Greece from germinal (precursor) form denoted as "speculative fiction". Somewhat dialectical, consensual and artistic approaches present in Fragments of Heraclitus (2009) and Tao-te-tiang of Laozi (1997) then possibly represented ideal forms near boundary line between "speculative fiction" and TE. Though the first TE arose in antique Greece (possibly Atomic theory of Leucippus and Democritus), their **maturated forms** appeared only during Modern Period (Míček, 1981). More precisely, the two physicists and natural philosophers markedly contributed to development of TE. Galileo Galilei used his exactly formulated TE in 16th and 17th century, whereas H.C. Oersted was the first who tried to retrospectively define TE in the first quarter of 19th century (Witt-Hansen, 1976; Míček, 1981). TE represented a considerably differentiated form of exact scenario-like speculation comprising reasonably acceptable versatile images concerning an investigated act, which specifically participates as an important dynamical component in many observed processes. However during later part of 19th century, usage of TE expanded to other areas with educated people occurring outside critical voices of philosophers and exact scientists. This even resulted in the reverted situation where almost any speculation was wrongly recognized as original scientific TE. In contrast, **masterly formulated TE** in natural science maintained their exact forms in the following history, e.g. those formulated by J.C. Maxwell in the third quarter of the nineteenth century or A. Einstein, E. Schrödinger and R.P. Feynman in the twentieth century (Brdička & Dvořák, 1977; Jost et al., 2009; Apertet et al., 2014).

According to Míček (1981), younger **sci-fi** differentiated from the same "speculative fiction" like TE only in Modern Period. This means that sci-fi differs from TE in (i) purpose, including among others frequent less exact ("liberated") relationships to reality and (ii) its "second parent", i.e. older fantasy. Consequently, inspiring artistic sci-fi represents ideal form distinct from TE. Nevertheless, sometimes but rarely, TE or its germinal forms can occur inside some sci-fi novels mostly written by authors having their own scientific experience (e.g. A.C. Clark) or deep knowledge about scientific or technical progress (e.g. J. Verne; in agreement with Wiltsche, 2019). Except for some illustrative TE or TE with freely eligible typical objects (see below), recent TE and sophisticated experimental designs (**SED**) terminally diverged. This followed from difficult, expensive, extensive and sometimes only partially or completely impossible (e.g. in evolutionary approaches and under inaccessible conditions) concretization of TE to current decisive networks of laboratory/empirical experiments and/or observations (Ado et al., 1981). Nevertheless, certain parallelism between TE and SED still exist and often concerns new or unusual (frequently hypothetical), unexplored, surprising, possibly unacceptable, model, unclear, uncertain, suspiciously too sure or only partially verified limiting situations.

Abstract-object-related specification of TE deduced from the historical reconstruction of TE development (Míček, 1981) yields better defined TE or opportunely also HMT (see below) including **consensual**, i.e. **typical** or **ideal**, objects (cf. "abstract objects" in **Table 1**). In fact, TE-specific abstract objects mostly reflect some necessary conditions and simplifications of modeled reality. More archaic but still valid **typical objects** represent variously strictly selected examples of actual objects. The strict selection of the typical object then reflects low degree of freedom in the investigated process. For instance, Gallileo's law of inertia was derived with the help of typical objects, when describing the motion of masterfully crafted ivory sphere on Venetian mirror (Míček, 1981). The second type of abstract objects, i.e. **ideal objects**, arise in processes called as (i) idealization based on simplifying scientific conventions (e.g. the "point particle" defined in Newtonian mechanics in 17th century; Šolcová, 2017), (ii) statistic processing appearing in 19th century (e.g. kinetic theory of gases, Brdička & Dvořák, 1977), (iii) professional and systemic evaluation of sufficient volumes of knowledge (e.g. knowledge-based objects representing idiotypes, epitopes, mimotopes known in immunology and interactomics; Kubrycht, 1985; Kubrycht et al., 2012; Landmann et al., 2017) and (iv) rare cases of sophisticated symbolic abstraction or artificially modified objects (cf. section "abstract objects" in **Table 1**). The important example of TE with sophisticated symbolic ideal objects is Maxwell's demon from 19th century (Brdička & Dvořák, 1977). Hidden exactness of this TE consists in substitution of the demon by more realistic objects or in its consistent step-by-step rejection (e.g. investigation of Maxwell's demon in the context of quantum thermodynamics of information; Cottet et al., 2017). The specification of TE including abstract objects does not mean that we have to start formation of TE only after object formation. The alternative ways of TE development can consist in skeptical object reformation after: (i) considerations near TE (see e.g. section "specificity" in **Table 1**) or (ii) processing of ideas or fundamental questions following from inspiration sources including those in chapter 7.

Table 1. Some connections important for thought experiments.

Aspects	Specifying notes[1]	Recommendations, details and questions[1,2]
Abstract objects	*Occurrence of TE-specific abstract objects in TE represent an important (the question is how necessary) assumption of TE definition (cf. chapters 2, 10 and **Figure 1**). *Two main groups of TE-specific abstract objects exist, i.e. typical and ideal objects (Míček, 1981; chapter 2). *Ideal objects can be further classified as conventional, statistic, knowledge-based, modified and sophisticated symbolic (extended in accordance with primary classification of Míček, 1981).	*The important question concerns contemporary accuracy of TE-specific knowledge-based objects and their possible future better formalization or re-formalization, e.g. via novel abstraction trends concerning AM (see section Abstraction) or using new scientific conventions. *The question concerns more precise specification of relationships between (i) abstract objects in TE and (ii) computer-related abstract objects (formalized object models, i.e. **FOM**) or design patterns. We can only propose that generation of modified abstract objects in TE can occur via similar ways like in cases of FOM. *Some abstract objects can be derived based on inspiringly interesting patterns mentioned in chapter 7.
Abstraction	*Abstractions occurring during assembly of TE frequently concern formation, specification and reasonable simplification of abstract objects mentioned above. *Abstraction and reasonable simplification of scene or scenario can be also sometimes useful for TE creation. Rarely, TE-related objects, scenes or scenarios undergo to "experimental" modification.	*Question arises, whether the fundamental concept of knowledge-based abstract models (**AM**) (Newell, 1982; Clancey, 1985; Wielinga & Schreiber, 1990) could be at least partially suitable for generation of possible knowledge-based version of TE. *Biothermodynamics, informatics, linguistics and methodological concepts related to developmental processes represent sources of knowledge and formalization important for formation of TE in biology (Kubrycht, 1985). *Scenes and abstract objects are necessary for operations in mind or auxiliary illustrations.
Dimensions	Each set-related dimension of TE is composed of several discrete classification terms denoting the corresponding usually disjunctive dimensional subsets or even their disjunctive subsets (i.e. subsets of the second order).	The two individual dimensions of TE correspond to purposes and variants of TE-related abstract objects (i.e. typical objects and all versions of ideal objects; cf. section Abstract objects). Additional (the third) compatible dimension then follows from structurally based schemes restricting TE subsets (**STES**; Yeates, 2004). In summary, the described soberly chosen three dimensions for now allow each individual TE to be classified as an element of a three-dimensional matrix.
Intelligibility	Lucid, consistent and sometimes reasonably simplified presentations are important for the possibility of friendly scientific discussion.	*Examples of concrete TE can improve intelligibility of the proposed STES. *For too complex TE, their illustrative forms, corresponding power point presentations or videos seem to be optimal for possible explanation and discussion.

Continued

Prehistory	If possible, it is useful to study or consider germinal principles preceding formation of ultimate antecedent or the corresponding separately investigated ancestor structure.	*Consensus-based evaluation, various comparative procedures and philosophically derived structurally-genetic approach represent suitable methods sometimes cooperating with TE in prehistory research (Černík et al., 1980; Kubrycht et al., 2006; Kubrycht & Sigler, 2020).
Specificity	*Due to history of TE (chapters 2 and 10), certain problems sometimes exist when distinguishing between TE and other related types o methods (for details see the corresponding part of right column). *In principle specific but widely usable (consensual) TE (cf. chapter 2) or products of their further processing (see **Figure 1**) are frequently successful. *Proposed STES have to substantially reciprocally differ in principle and this should be markedly reflected by their schemes. *It is a question whether each individual TE or only most of TE can be specifically described by at most unique STES.	*Overall/complex descriptions of concrete processes looking like TE are correctly denoted as AM, scientific forecast or historical if not police reconstructions. Similarly, it is necessary to distinguish matter-of-fact descriptions from TE. For valuable considerations only distantly reminding TE, the expression "clever speculation" fits. *TE-related experimental routines or sophisticated experimental designs, retrospective scientific/philosophical typification of observed events or some derivatives of inductive logic are mostly incorrectly considered as TE. Nevertheless, these approaches sometimes inspire TE formations or can be reformed to TE after successful modification. *There is a question STES limited to the specific scientific-area can exist. *If necessary parameters or markers are known, possible improvement of STES specificity could follow from (i) historical reconstruction of TE development and subsequent construction of approximate tree (cf. Míček, 1981) or (ii) the corresponding network analysis.
Timing	Author's history, presence, future regarded in TE and the intervals of virtual process times passing during TE have to be always correctly and lucidly distinguished when forming TE or restricting STES.	TE including only unique interval of virtual process time in the present constitute the subset containing simplest forms of TE (cf. Galileo's TE mentioned in chapter 2) corresponding to the simplest variant of STES.

[1]STES—schemes restricting TE subsets; TE—thought experiment(s); *—indicator of alternative notes concerning the same table section.
[2]AM—abstract model(s) (see chapter 3); FOM—formalized object models.

Independently of considerations following from the discussed historical reconstructions, graphic clarification (i.e. the corresponding drafts pictures, power point presentations etc) and understanding to TE diversity appear to be important for **TE creation**. An important type of diversified **TE classification** follows from different purposes of TE (cf. **Table 1**; Míček, 1981). TE can (i) lead to the formation of MH described below (e.g. derivation of Maxwell-Boltzmann distribution of molecular rates in gas; Brdička & Dvořák, 1977) or AM (in agreement with the immediately following point), (ii) enable to formulate non-trivial questions or considerations important for further organizational (Aguinis et al., 2023), experimental or theoretical work (e.g. Maxwell's demon; Brdička & Dvořák, 1977), (iii) reasonably warn in cases of contradictions in theory (Míček, 1981; cf. also counter-thought-experiment in Yeates, 2004; differently from decisive critical empiric experiments initiating crisis of paradigm, these warning/critical TE are not solely destructive for paradigms), (iv) compose combinations or more complicated arrangements of differently intellectually-based processes including TTM (e.g. derivation of molecular orbitals for more complex molecules; Brdička & Dvořák, 1977), (v) forming set of alternative TE representing starting points for possible future research (Burge et al., 1979), and (vi) simply illustrate considerably tortuous problems. Certain problems with authenticity can sometimes follow from the fact that the last purpose-related variants of TE (illustrative TE) cannot be accurately distinguished from the first one (generative TE, i.e. TE frequently generating MH). More detailed structural classification of TE was based on schemes restricting TE subsets (**STES**). This important concept appeared online only after millennium (Yeates, 2004) and was also recently presented in Wikipedia page concerning TE. Several opinions and glosses concerning STES are displayed in **Table 1**. Recent approximate classification correlates age of theory (only young and old theories have been yet distinguished) with relationship of TE-forming author to this theory (Aguinis et al., 2023). This classification and accompanying logical scheme could help us with orientation when building at least some TE or the related AM.

3. Description of Additional Classical TTM

Differently from TE and fundamental MH (see chapter 6), abstract models (**AM**) constitute as much as credible but still simple descriptions of concrete processes to approximate their complexity and simultaneously to avoid frequent errors, respectively. In the cases of **approximating/preliminary** model descriptions we can distinguish four subtypes of AM. (i) **Non-living physical 3D models** are AM as possible plausibly imitating necessary space properties of modeled actual objects (e.g. 3D model of DNA described by Watson & Crick (1953)). (ii) **Gross models** are based on very limited structural knowledge represented by schemes, formulas, symbolic chain changes or 2D projections. These AM currently enable us to get initial orienting information about the tortuous problem or as yet little known reality (e.g. Kubrycht & Novotná, 2014; in this case we met the problem of prevailing difference between autoepitopes containing mainly aliphatic amino acids and well predictable epitopes). (iii) **Black box** analysis comes from knowledge of behavior only (Sarbaz & Porakbari, 2016; Terayama et al., 2021). (iv) **Gray box** analysis then uses weak but existing knowledge concerning both structure and behavior of modeled objects (Oussar & Dreyfus, 2001; Sarbaz & Porakbari, 2016). Modern advanced **mostly computer assisted complex AM descriptions** frequently comprise systemic analysis involving rules from graph theory (Kolář, 2009), object-oriented programming using abstract objects denoted as formalized object models (**FOM**) and sometimes also design patterns or universal modeling language (Gamma et al., 2003; Fowler, 2009; Bohmer, 2012).

Mathematical hypotheses (**MH**) constitute TTM important for recent physics and some interdisciplinary areas of natural science. MH consistently reflect quantitative relationships observed in nature without sensory-based visualization using usually formulas or equations (Ado et al., 1981). In contrast to mathematics dealing with consistent description of any postulated, estimated or idealized shapes and their frequently countable or logically derived relationships, MH describe real processes occurring under certain justified background conditions and use experimentally correlated constants (cf. Barrow, 1997). This requires not only sufficient quantitative and structural agreement of MH, but also certain knowledge about contemporary scientific progress in investigated areas. MH frequently arise via **at least three following mechanisms**. (i) MH can be generated based on relationships present in the corresponding TE, certain AM or Mp, valid schemes or several approximate empiric formulas (Míček, 1981; Brdička & Dvořák, 1977). (ii) If new suitable calculus or transform is generated in mathematics, it is necessary to specify important relationships in which this novelty will be successfully used (e.g. usage of infinitesimal calculus or Fourier transform; see chapter 8; Štecha, 2003; Klíč et al., 2012; Šolcová, 2017). (iii) Two distinct MH can be sometimes unified to form a more general solution, e.g. when formulating Schrödinger equation (cf. chapter 9) or local biothermodynamic version of the first law of thermodynamics (Dvořák et al., 1982).

Freely considered term scientific metaphor(s) (**Mp**) concerns not only symbolic objects, but also structurally or dynamically intended judgments following from analogy (Brdička & Dvořák, 1977; Stachová, 1993). Such Mp can considerably contribute to the generation of some TE, because they (i) participate in the formation of typical objects and can influence the formation of ideal objects, (ii) sometimes help with building TE-related scene or specification of scenario (Míček, 1981) or (iii) enable us to select mathematical description based on structural or dynamic similarities (see chapter 9). In addition, Mp yield qualitative predictions, orienting concepts (cf. chapters 8) and sometimes enable usage of existing approaches for other purposes, i.e. **metaphorical transference** (e.g. lytic unit of NK cytotoxicity as generalized Michealis' constant for enzyme kinetics; Pross & Maroun, 1984). It can be noted that poets as the most frequent producers of Mp create some of their poems in intervals of seconds or minutes, whereas writing up other poems may take even years (statement of the Czech poet M. Holub). This implies the question whether scientific Mp can be similarly to poetic ones formed by different forms of intellect.

4. Newly Proposed Hybrids of MH and TE

Hybrids of MH and TE (**HMT**) represent a more recent TTM proposed for theoretical natural science (Míček, 1981). The first pattern of HMT appeared during solution of black-body radiation by Max Planck in 1900 (Kleppner & Jackiw, 2000). This discovery started the era of quantum physics (Brdička & Dvořák, 1977). In case of HMT, TE and MH compose combined or more complicated arrangement of procedures (cf. purposes of TE in chapter 2). In comparison with TE, we can observe wilder (sometimes almost surrealistic) scene composing HMT. This scene opportunely includes modified abstract objects of TE, local rules, transformations (e.g. transformations from Euclidean space to space reflecting string theory; Barrow, 1997), various mathematical projections (Lakatos, 1976), stochastic schemes (Unčovský, 1980), numbers and characters. Characters play an important role in many bioinformatics considerations (occurring sometimes on boundary lines of TE and HMT), because words above alphabet (e.g. motifs, consensi and synonymous functionally related segments, etc.) frequently form primary components of the corresponding objects (Chytil, 1984; Alberts et al., 2008; Kubrycht et al., 2013). Such bioinformatics words represent mostly nucleotide and protein sequences, whereas the corresponding observed or potential changes can be denoted as formal grammar-like records and classified as existing or potential statistical events of various structural or functional importance, respectively (Rogozin & Kolchanov, 1992; Hatina & Sykes, 1999; Kubrycht et al., 2006, 2016; Duquette et al., 2007). Diversification of scientific scenography in HMT appears to be interesting with respect to the possibility of **reverse abstraction** (i.e. structurally based depicting abstraction close to modern painting) important with respect to intended future applications of artificial intellect. This could make more clear formalistic or only executing schemes sometimes necessary for understanding to some theoretical papers or development of proposals.

5. Computer-Assisted TTM

Provided that substantial decision/evaluation is not performed out of selected set of programs, we can speak about computer-assisted AM. On the other hand, if outer substantial decision/evaluation is based on TE, MH or HMT, we can refer computer-assisted MH, TE, HMT, respectively (cf. e.g. Möller & Schenck, 2008). At least the two last preceding alternatives and some AM (mostly simulations) are sometimes alternatively denoted as computer experiments (**CE**). The question concerns existence of **autonomous group** of CE different from other TTM. Computer-assisted Mp appear to be interesting topic for recent and future research of artificial intellect.

6. Floors of Theoretical Science

Three stages related to grading of theoretical science are denoted as **T0**, **T1** and **T2**. **T0** constitutes more likely a group of candidates for theory forming thus frequently criticized basement of theoretical science. These candidates include gross estimations, immature hypotheses, guesses, presumptions etc. Nevertheless, some of these theoretical candidates can represent starting points of subsequent important scientific research. **T1** comprises correct empiric hypotheses (frequently described in methodology of empiric science), AM, some MH and abstract objects used in theoretical science. In T1 stage, theoretical principles develop from empiric data and pieces of knowledge and analytical character of knowledge predominates (Černík et al., 1980). New hypotheses and designs for experimental verification appear. AM become to be continuously perfected, better formalized and generalized when adding parameters and new conditions or refining formalized object models. Ideal objects mature, relatively accurate Mp and typical objects are proposed or reconsidered. Numbers of approximate empiric formulas or more versatile MH and concrete AM are increasing. TE are proposed, whereas some failed attempts to create an adequate TE are replaced by HMT to attain important solutions. Newly formulated laws then represent specific manifestation of **T2** stage (only T2 in further text). Laws often **expand to consistent theoretical systems** via hypothetical-deductive way (for details see below) in which the synthetic character of knowledge prevails (Černík et al., 1980). As follows from the **Theory of Paradigm**, laws are pragmatically substituted by their more precise and general followers during crisis of paradigm. This substitution requires formation of new T0- and/or T1-related representatives (Kuhn, 1962; Lakatos, 1970; Míček, 1981; Fajkus, 1997).

In **T2a** level of T2, **factual/empiric laws** constitute the most frequent theories (Černík et al., 1980). For instance, such laws include (i) geographical relationship indicating movement of continents (A. Wegener), (ii) qualitative important table-related arrangement of data (Mendeleev's periodical system) or (iii) descriptions of typical morphology accompanied with structurally-functional descriptions (cell theory; M.J. Schleiden and T. Schwann). Factual/empiric laws can arise via different manners, i.e. based on observations, experimental experience or when using TE or Mp, various forms of abstraction, data representations, data processing including statistical, systemic or structural analysis. These laws can expand to **systems of logical or fuzzy-logical rules** associated with knowledge-based topologies, hierarchies, networks or lists of statistical linkages sometimes forming factual ontological data system (cf. Devkota et al., 2022).

Only theories in physics and some interdisciplinary branches combined with physics, mathematics or informatics can be classified by means of the **level T2b** (only T2b in further text; cf. Černík et al., 1980). For instance in biology, this concerns biomatematics, biophysics, bioinformatics and biothermodynamics. **Idealized laws** are most frequent entities in T2b. Idealized law begins its own existence at the time, when unique so-called **fundamental MH** or several such MH expressing this law is/are formulated. Fundamental MH usually represents substantial and widely usable MH frequently (cf. Ado et al., 1981). Differently from factual/empiric laws, **expansion of idealized laws yields mathematically consistent systems** (networks) of MH, i.e. formulas and equations. **Generalized laws** comprise mostly generalized idealized laws. Like current idealized laws, generalized idealized laws achieve T2b level and are mainly expressed using differential equations. The first generalized law, i.e. Euler-Lagrange equations, arose in 18-th century whereas most of such laws appeared in last hundred years (Lehner & Wendt, 2017). Generalized laws concern also biological processes, e.g. law of generalized diffusion (Murase & Matsuo, 1991) and local biothermodynamic version of law of energy conservation (Dvořák et al., 1982). The question is whether at least some advanced and verified descriptions comprising formal grammar-like developmental processes in special animal models draw near T2b (e.g. in the corresponding research of Caenorhabditis elegans; Larsson et al., 2011; Tarkhov et al., 2019; Ewe et al., 2022).

In summary, the development of theoretical research consists in formulation of still **more versatile, flexible and better abstracted** methods describing reality. Nevertheless, the usage of these methods for the description of complex events sometimes needs the return to graphic representations and schemes, more simple procedures and searches for new completing views. Accessible consistent mathematical description and formation of quantitative networks constitute undisputed advantage of theories.

7. Inspiration Sources for TTM creation

Certain objects in real world and some abstracted constructs can be considered as inspiringly interesting patterns (**IIP**) when forming abstract objects usable in certain AM, TE and HMT. This concerns mainly IIP reflecting **principles important for progress** in history of knowledge and science. The list of such IIP comprises quantum computer, representing recent paradigmatic object (Barrow, 1997), water and related more general and "more chaotic" theoretical constructions of events occurring in superfluids (Kapitza & Lifshitz, 1969; Scott, 2022), language as medium/means of speech and reflection of the world (including e.g. biological sciences), Turing machine, cellular automata (Ermentrout & Edelstein-Keshet, 1996), translating, decoding or decrypting programs or hardware components, astronomical clocks, etc.

Dual chimeras separately approximate double-dealing behavior of observed objects (**Table 2**). More precise dual descriptions then usually comprise unifying attempts, i.e. (i) solutions of differential equations like Schrödinger equation (i.e. MH; Brdička & Dvořák, 1977), (ii) well interpretable TE, HMT, (iii) some co-routine-based computer simulations concerning delayed, diffusive or sometimes almost immediately (infinitesimally) reciprocally communicating or responding processes (i.e. AM or MH), (iv) verified formal grammar-like relationships (mostly AM or MH; cf. Chytil, 1984), (v) valid structurally-statistic linkages reassessing or specifying AM, MH or HMT (Janout, 1995; Lepš & Šmilauer, 2016) and (vi) considerations based on observed dialectical relationships, cyclic processes or more specific system of changes near life comprising structure associated with information, fluctuation linked to noise and function requiring energy (Prigogine, 1978).

Due to an extensive usage of computers, the number of various **graphical presentations** increased including current graphs, 2D (frequently map-like pictures) or 3D (space or space-like) representations. These attempts evoke an image of futurological scene in which very intelligent computer offers to tested or only scared scientist its cleverest variants of representations: "Please, make your choice".

Table 2. Examples of interesting dualities in natural science.

Objects of DC[1]	FC[1]	Components of DC[1]	Characterization	Notes and comments[2]
		(i) Complementary dualities		
Elementary particles	A	Particle	Material quantum of constant inertial mass	*Initially, the duality of photon was described when investigating black body radiation.[3]
	B	Wave	Wave lengths and refraction	*Formulation of Schrödinger equation became to be necessary for structural modeling of atoms and molecules.[3]
Biomembranes	A	Liquid mosaic	The model description included affinity interactions forming clusters of membrane molecules. The structure of these clusters can be dynamically changed in response to external stimuli via biochemical reactions or by means interactive cross-linking (Singer & Nicolson, 1972; Alberts et al., 2008).	*Model of biomembranes reflecting their duality was proposed (Zeng & Li, 2011). *Multiple liquid crystal states dependent on temperature values were described in individual cases of chemically prepared liquid crystals. In accordance with these observed model changes, consistent increase of biomembrane fluidity accompanied by the corresponding increased activities of certain immune functions or changes in sizes of mammalian cell subpopulations has been observed in response to fewer (Mace et al., 2011; Kobayashi et al., 2014; Zynda et al., 2015). However the direct evidence of liquid crystal changes during fewer has not yet been presented.
	B	Liquid crystal	Formation of different gel and liquid crystalline biomembrane states depends on temperature changes, sound waves, neurotoxic non-receptor interaction of amyloids with cellular membranes during Alzheimer disease and perhaps also on infrared radiation (Helfrich, 1973; Fenske & Jarrell, 1991; Buchsteiner et al., 2010; Hirai et al., 2013; Lewicka et al., 2017; Bolmatov et al., 2020).	
		(ii) Mutually intergrowing dualities[4]		
Evolution of complex cognition	A	**E-loops**	Network forming pathways of response to elementary signal source	*Gene duplications, recombinations and mutations, slippage mechanisms or other phylogenic changes in molecular (DNA, RNA or protein) segments variously responsible for molecular function or regulatory modification play important role in "interlaced" co-evolution of E-loops and EL-coordination (Wilson et al., 1998; Alberts et al., 2008). *The oldest declaration of E-loops comes from Laozi (1997) living in 6th century B.C. The exact examples of E-loops can be seen in the book of Alberts (2008).
	B	**EL-coordination**	Crossing pathways of molecular signaling, expression of genes in cell nuclei, variously specific cell-cell communications and actions of specific organ centers (brain, endocrine system, bone marrow, etc.) can participate in coordination of overall or local responses of organisms to complex sources of multiple signals. These crossing pathways complete individual networks of E-loops.	

Continued

Relicts of nucleo-organisms in question	A	Nucleo-organisms	Nucleo-organisms (**NO**) were extinct organisms containing only nucleic acids but not proteins. They are considered as ancestors of proteo-organisms (Smith & Szathmary, 1995). Time interval of the presumed NO occurrence is unknown, which brings interesting conjectures (e.g. origin in the time of previous sun, when assuming NO occurring deeply under planet surface in time of nova explosion).	*Various amino-acid derivatives of RNA occurring in primitive PO are assumed to be relict traces of transition organism forms between NO and PO when considering trends to spread original recognition repertoire of nucleic acids in NO (Smith & Szathmary, 1995). *It is a question, whether evolution of nucleic acids in PO maintained or integrated old mechanisms of NO origin. This question also concerns the puzzle of necessarily synchronous changes in chromosome numbers occurring from time to time during evolutionary diversification of species.
	B	Proteo-organisms	Proteo-organisms (**PO**) are current organisms synthesizing proteins based on genetic code.	
Cells composing multi-cellular organisms (**M-cells**)	A	Living elements	Behavior of some M-cells occasionally looks like that of unicellular organisms (for some details see the corresponding text in right column).	Mainly vertebrate immune cells and cancer cells dissociate from cell-cell conjugates or tissue agglomerates via different mechanisms like protozoans (Alberts et al., 2008). Proliferation of these cells frequently exceeds current status of cell population/subpopulation renewals. Some of these cells undergo unusually frequent and differently specific hypermutation (Rogozin & Kolchanov, 1992; Dörner et al., 1998; Duquette et al., 2007; Roberts & Gordenin, 2014; Hu et al., 2015; Shilova et al., 2022).
	B	Components of organism	Certain mechanisms of M-cell growth suppression, tissue nourishments and multilevel protective or self-protective machineries exist. In addition, admirable relationships between mitosis and M-cell death contrasting with usual expansion of unicellular organisms can be often observed.	

[1]DC—dual chimeras separately approximate double-dealing behavior of observed objects; FC—formal description of any two components forming dual chimeras, when using lucid symbolic characters A and B. For abbreviations or terms E-loops, EL-coordination, M-cells, NO, PO see inner space of this table.
[2]For possible variants of duality descriptions see chapter 7.
[3]For details see chapter 9 and **Table 3**.
[4]This type of dualities requires more complicated descriptions which makes difficult to use mathematical hypotheses.

Though **IT principles** represent important inspiring source for natural science, the inspiring processes and structures in nature and in computers somewhat qualitatively and quantitatively differ. This means that mechanistic transfers of rules and algorithms do not always hold being sometimes even waiting for further progress in informatics. This is the reasons why some important philosophical questions concerning natural processes are still rather solved using biothermodynamics or reaction kinetics though using computers (for details see chapter 9).

Among the effective manners of **less exact but still important inspiration**, we can find (i) our own or acquired by reading (mainly modern fantasy and sci-fi constitute topical sources) imagination, (ii) certain principles, connections and events described by architects and mystery scientists, (iii) various stories, myths and fairytales, (iv) certain games (e.g. chess, Go, Sudoku) or (v) shapes observable in maps, music, ornaments, building constructions and products of plastic arts.

8. Concise History of TTM and Their Implementations

The simple MH and AM were possibly formulated in time of beginnings of astronomy and geometry in **Sumer** and **Egypt** (Asimov, 1994; Steele, 2019). Lately, **Greeks and their Byzantine descendants** became serious and most frequent authors of TTM during Antique period and early Middle Ages, respectively. In addition to examples displayed in **Table 3**, we have to mention new rules, if not rediscoveries, in geometry (e.g. Thales of Miletus, Pythagoras and Euclid) and logic (mainly Aristotle) important for further development of TTM (Aristotle, 1961; Kessidy, 1976). Subsequently, **Persians and Arabians** contributed with their new opinions to development of theoretical natural science (e.g. Al Kindi (Alkindus), Ibn Miskaway, Ibn Sina (Avicena), and Alhazen; for Ibn al-Nafis see **Table 3**; Ado et al., 1981; Hehmeyer & Khan, 2007). In the 13th and the 14th centuries, the reports about Chinese discoveries (e.g. Million of Marco Polo) and immigration of Byzantine scholars contributed to **Italian Renaissance** (Martin, 2023). Multiple physical 3D models and AM-related drafts of Leonardo da Vinci (e.g. Richardson (2019) or Marusic & Broomhall, (2021)), rediscovery of heliocentric system by Italian student and Polish scientist Nicolas Copernicus as well as some opinions of young Galileo Galilei constituted in fact initial manifestations of **European rationalism** in the end of the 15th and during the 16th centuries (**Table 3**). New Organon published by Francis Bacon in 1620 then became to be turning point in history of science. Hence this book specified inductive methods, requiring experimental verification of the proposed hypotheses concerning actual world (Ado, 1981). Further development of TTM was markedly influenced by Rene Descartes. His contribution among others included: (i) important and perhaps dialectical relationship between radical skepticism and constantly verified experience ("Experientia"), sometimes accompanied by reasonable doubt about radical skepticism (Major & Sobotka, 1977) and (ii) a new useful and lucid manner how to record explicitly defined mathematical functions (Šolcová, 2017). Discovery of **infinitesimal calculus** performed independently by Isaac Newton and Gottfried W. Leibniz in the second half of the 17th century represented strategic point for further development of fundamental MH namely in area of physics (Šolcová, 2017). This revolutionary calculus enabled for mulation laws of Newtonian mechanics (in the 17th century), Euler-Lagrange equations representing **generalized law** of mechanic (in the 18th century), Maxwell's equations representing law describing **electromagnetic field** (in the 19th century) and later fundamental MH mentioned in **Table 3** and chapter 9. In the 18th century, the multiple new formal mathematical models were derived and lately used in more concrete AM in several disciplines (Šolcová, 2017; **Table 3**). During 19th century, TE were successfully used not only in physics but also in **chemistry**, whereas MH were formulated in biology (**Table 3**). The first HMT appeared only in the year 1900 (see **Table 3** and chapter 4).

Table 3. Historical examples of the discoveries implemented using TTM.

(a)

CL[1]	Author	Country[2]	TTM[3]	Significance[4]	Comments[4]
−5	**Leucippus** + **Democritus**	possibly Abdera in Greece	TE	Atomic theory (Ado et al., 1981; Berryman, 2022)	This is possibly the first known use of TE in history (Míček, 1981).
−3	**Aristarchus**	Samos in Greece	AM	Gross heliocentric model (Ado et al. 1981)	This model was based on observations of Month and Antiquity Greek geometry.
	Archimedes	Syracuse (Greek Sicily)	MH	Principle of buoyancy (Ado et al., 1981; Bečvář, 2012)	*Possibly the oldest law in physics *Also the description of balance on the cage
6	John **Philoponus**	Eastern Roman Empire (Early Byzantium; recent Egypt)	TE	Theory of impetus-impetus was represented by the two expressions, i.e. kinetic capacity (dynamis) and kinetic force (energeia). Force is transmitted directly from mover to the body moved (Van Dyck & Malara, 2019; Wildberg, 2021)	*Theory of impetus represents precursor of Newtonian mechanics, i.e. the first theory achieving the level T2b (cf. chapter 6). *This theory was further processed by J. Buridan (rector of Sorbona and co-founder of Kraków Academy) and J. Cantius (teacher working in Kraków Academy) in 14th and 15th centuries, respectively.
13	**Ibn al-Nafis**	Mamluk Sultanate (recent Syria)	AM	Model of pulmonary circulation of blood (Hehmeyer & Khan, 2007)	*Model was deduced after several dissections of dead human bodies. *Rediscovered by W. Harvey in 17th century
15	Leonardo **da Vinci**	Toscana (recent Italy)	AM	Multiple physical 3D models interesting with respect to mechanics (see e.g. Richardson (2019) or Marusic & Broomhall (2021))	*Heart as a muscle pumping blood (Shoja et al., 2013) *Discovery of rising by absorption
16	Nicolas **Copernicus**	Poland	AM	Rediscovery of heliocentric model using contemporary trigonometry (Asimov, 1994; Kokowski, 2006)	Copernicus was possibly influenced by manuscripts of J. Buridan and J. Cantius dealing with the theory of impetus and located in Krakow.

Continued

17	Galileo **Galilei**	Toscana (recent Italy)	TE Mp	TE generated factual Law of inertia (chapter 2) reformulated as MH by I. Newton Mp enabled formation of typical objects in Galileo's TE. (Míček, 1981)	*Semi-quantitative description of gravitation (Machamer & Miller, 2021) *Philosophical concepts for modern theoretical science (Ado et al., 1981) *Galileo referenced theory of impetus (Van Dyck & Malara, 2019).
	Johannes **Kepler**	Holy Roman Empire (recent Germany)	MH	*Laws of planetary motion using numerical analysis (Thorvaldsen, 2010)	Kepler's laws included discovery of elliptic motion of the planets and their countable dynamics.
	Christian **Huygens**	Dutch Republic	Mp	Light as wave (Huygens principle; Aspect, 2017)	*Author of early sci-fi (Stableford, 2003)
	Isaac **Newton**	England	MH	*Laws of motion *Law of universal gravitation (Ado et al., 1981)	*Discovery of integral calculus (Šolcová, 2017) *Philosophy concerning theoretical mechanics *Mechanistic explanation of Kepler's laws
18	Leonard **Euler**	Swiss Confederacy	AM MH	Multiple mathematical models Geneneralized equation for mechanics (cf. Lagrange)	*Importance for future statistics, medicine, informatics and architecture (Kolář, 2009). *Contribution to the graph theory (Kolář, 2009).
	Carl **Linnaeus**	Sweden	AM	The first partial model of taxonomic system (Calisher, 2007)	The model used morphological markers and was later re-evaluated in consequence of Darwin's theory and sequence-based taxonomy.
	Joseph L. **Lagrange**	Kingdom of Sardinia (Torino in recent Italy)	MH	Lagrangians – kinetical potentials of system (Lehner & Wendt, 2017)	Generalization of Newton mechanics using Euler-Lagrange equations based on Langrangians. In contrast to Newton mechanics, this MH does not require additional geometrical diagrams.
19	Thomas R. **Malthus**	England	AM	Gross exponential model of population growth (Stutz, 2014)	Malthus was primarily concerned with economics.
	John **Dalton**	England	MH	Atomic theory – concept of atomic weights (Brdička & Dvořák, 1977)	Concept based on Proust's law of definite proportions (possibly MH generated by TE)
	Hans Christian **Oersted**	Denmark	TE	The first definition of TE (Witt-Hansen, 1976)	Discovery of electromagnetism (Martins, 2003)

Continued

	Pierre Francois **Verhulst**	Belgian	AM	Gross logistic model of population growth (Stutz, 2014)	Mathematical studies important for development of logistic regression
	Gregor Johann **Mendel**	Austrian Empire (recent Czech Republic)	MH	Mendelian laws of inheritance (Hatina & Sykes, 1999)	Laws were derived based on rounding off enumerated empiric fractions, i.e. in agreement with empiric statistics.
	James Clerk **Maxwell**	Scotland	MH MH TE	Maxwell's equations (**ME**) Kinetic theory of gases Inspiring Maxwell's demon (Landau & Lifshitz, 1973; Brdička & Dvořák, 1977)	*ME represent laws of electromagnetic field. *Kinetic theory of gases constitutes (i) TE-generated MH and (ii) mechanistic form of chaos. *Maxwell's demon is still investigated (Cottet et al., 2017).

(b)

CL[1]	Author	Country[2]	TTM[3]	Significance[4]	Comments[4]
20	Max K.E.L. **Planck**	German Confedera-tion	HMT MH	Black-body radiation Planck units (e.g. length or time) (Tomilin, 1999; Kleppner & Jackiw, 2000)	*Comments to philosophy of natural science *Nobel Prize in Physics for his quantum theory (1918)
	Leonor **Michaelis**	German Empire	MH	Fundamental equation for enzyme kinetics completed with lucid linear representation (Michaelis et al., 2011)	*M. L. Menten was co-author of this MH. *Equation can be generalized for a large number of enzyme reactions and their inhibitions (Horák & Kotyk, 1977).
	Albert **Einstein**	German Empire	MH	Special and universal theories of relativity changing opinions following from Newtonian physics (Landau & Lifshitz, 1973; Boček, 1976)	*Discovery of photoelectric effect *Space curved with gravity, speed changing masses, lengths and time intervals *Application of tensors in the curved Riemannian space *Nobel Prize in Physics (1921)
	Robert S. **Mulliken**	USA	MH/ HMT	Molecular orbitals (Mulliken, 1967)	*Electrons as common waves of molecules but not atoms *Nobel Prize in Chemistry (1966)
	Ervin **Schrödinger**	Austria-Hungary (recent Austria)	MH	*Schrödinger equation (**SE**) derived using Mp (Brdička & Dvořák, 1977)	*SE is fundamental MH necessary for theoretical as well as semi-empiric quantum-physics-based predictions of molecular structures (cf. chapter 9). *Nobel Prize in Physics (1933)

Continued

Niels Kay **Jerne**	England/ Denmark	AM/ TE	*Immune (idiotypic) network - antibodies interact with both specific antigens and variable regions of other antibodies using the same site. This forms interactive network (Jerne, 1984).	*Computer assisted versions of this AM develop only slowly due to complexity of the process, though the simplified abstract description via formal generative grammar is clear (Jerne, 1985). *Various usage of anti-idiotypic vaccines *Generalized to complex Ig-superfamily network (Odales et al., 2020) *Nobel Prize in Physiology or Medicine (1984)
Alan **Turing**	England	AM	Model of morphogenesis, starting the investigation of non-mechanistic chaos (cf. Maxwell in this table and chapter 9) (Turing, 1952)	*Turing is considered to be one of founders of theoretical computer science and artificial intelligence (e.g. Turing machine; Chytil, 1984). *Decryption of Enigma-machine messages in the Second World War
Ilya Romanovich **Prigogine**	Russian Empire	MH	Theory of dissipative structures (area of biothermodynamics) (Dvořák et al., 1982)	*Research of self-organizing systems including origin of life (Prigogine, 1978; cf. chapter 9) *Nobel Prize in Chemistry (1977)
Edward Norton **Lorenz**	USA	MH	Theory of deterministic chaos (originally important model of weather; Lorenz, 1963)	*A certain limitation of Butterfly effect consists in diffusion events (cf. chapter 9). *Problems with specificity of the deduced chaodynamical agnosticism.
Richard Phillips **Feynman**	USA	MH HMT	Theory of quantum electro-dynamics (Feynman, 1966) Feynman diagrams were derived as convention based on HMT (Kugler, 2018)	*One of the first investigators in area of quantum computers *Together with J. Schwinger and S. Tomonaga Nobel Prize in Physics (1965) concerning quantum electrodynamics
James Dewey **Watson**	USA	AM	Physical 3D model of DNA based on X-ray diffraction proposed together with F. Crick (Watson & Crick, 1953; Alberts et al., 2008)	*The model explained genomic reproduction based on nucleotide-base-complementarities. *Participation in human genome project (Green et al., 2014). *Together with F. Crick and M. Wilkins Nobel Prize in Physiology or Medicine (1962)
Radu **Bălescu**	Romania	MH	Liouville equation adapted for microscopic interpretation of thermodynamic systems (Balescu, 1975)	Substitution-based agreement of this equation with Schrödinger equation (Dvořák et al., 1982)

Continued

Gabriele **Veneziano**	Italy	AM/ MH	String theory (Rickles, 2014)	*Together with L. Susskind, J. Nambu and H. B. Nielsen—pioneer papers in string theory *Heisenberg's S-matrix represented important information for the development of string theory.

[1]Three main parts of this table represent three important eras, i.e. Antiquity, Middle Ages and Modern Period.
[2]Country—country of author's origin; England/Denmark—Danish immunologist born in London.
[3]AM—abstract model(s); AM/MH—Veneziano's model represented AM tending to become fundamental MH; AM/TE—conventional AM close to TE based on empirical knowledge; HMT—hybrids of MH and TE (cf. chapter 4); MH—mathematical hypothesis/hypotheses; MH/HMT—additional usage of TE and data re-evaluation, i.e. formulation of HMT, can be sometimes important in cases of molecular orbitals related to complex molecules Mp—metaphor(s); T2b—the highest level of theory (see chapter 6). For additional abbreviations see **Table 1** or Introduction.
[4]ME—Maxwell's equations; SE—Schrödinger equation.

In the first half of the 20th century, TTM appeared in novel quantitatively investigated braches of natural science such as **biochemistry** (namely enzyme kinetics), **theory of relativity** and **quantum physics** (see chapter 9 and **Table 3**). Certain **philosophical aspects of theoretical natural science** became to be analyzed by E. Husserl and N. Bohr (Ado et al., 1981). E. Husserl dealt with post-epochal processing of arising hypothesis including formulation of MH or AM. N. Bohr formulated methodological philosophy concerning quantum physics. The first materialistic evaluation of MH as a type of scientific method was subsequently performed by physicist S. I. Vavilov (co-author of Vavilov-Cherenkov radiation honored with Nobel Prize; Ado et al., 1981; James et al., 2011). In fiftieth, the **structure of DNA** was successfully modeled using specific physical 3D model based on data obtained in X-ray diffraction, i.e. by means of AM. This discovery represented the law explaining molecular reproduction of genomes (Watson & Crick, 1953; Alberts et al., 2008; **Table 3**). Later **tracing of protein interactions of steroid hormones** employed scientific Mp. In accordance with the results with individual steroid hormones, many analogous or even evolutionarily related transport and regulatory proteins were found, except for several imperfections (cf. Harper, 1977; Ganong, 2005; Wang et al., 2014). TE appeared more frequently in biology only in last decade of 20th century and later (e.g. Boregowda et al., 1997; Möller & Schenck, 2008; Falissard, 2011; Yamamoto et al., 2019; Krauzlis et al., 2023).

Early **computer processing** of natural scientific theoretical approaches occurred in fiftieth, sixtieth and seventieth of the 20th century. This processing comprised mainly current enumeration following form TE, MH and HMT systemically pre-processed to their computer-assisted forms (e.g. in cases of quantum mechanics, astronomy and enzyme kinetics; Brdička & Dvořák, 1977; Horák & Kotyk, 1977; Barrow, 1997). Lately in eightieth and ninetieth, further progress in programming, increasing rates of computer processing and large-volume memories including newly built knowledge-based databases

(**Table 3**) enabled marked progress in physics and molecular biology. The **progress in molecular biology** concerned mainly comparison and classification of still increasing numbers of protein and nucleotide sequences (e.g. Altschul et al., 1997), building of sequence-based trees important for molecular evolution (Felsenstein, 1981; Tateno et al., 1982; Saitou & Nei, 1987; Sourdis & Nei, 1988; Philippe, 1993), predictions of secondary and 3D structures and even the possible interactions of the corresponding molecules (Godzik et al., 1993; Rodionov & Johnson, 1994; Dunbrack, 1999). After millennium computer programs offer hybrid comparisons via crossing several independent methods (Kaur & Raghava, 2004; Standley et al., 2010), advanced molecular dynamics enabling more precise quantitative models of reactions or interactions (Lakhani et al., 2017; Sanapalli et al., 2022), similarly intended knowledge-based homologous 3D modeling (Evers et al., 2003; Clark & van Vlijme, 2008; Zhu et al., 2014; Arcon et al., 2021) and interactomic databases (Gemovic et al., 2019). Recent pandemic of COVID19 led to molecular dynamic studies of interactions between proteins necessary for reproduction of SARS2 virus and their potential high affinity natural inhibitors of plant origin (mainly certain flavonoids were selected; Ali & Kunugi, 2021; Chapman & Andurkar, 2022; Kashyap et al., 2022; Rahman et al., 2022; Toigo et al., 2023). The studies contributed to further **rationalization of traditional medicine** and selected molecules interesting for possible future therapies of coronaviral and other viral diseases using or combining existing or newly prepared nutritional supplements if not sophisticated diets.

Though artificial intelligence (**AI**) formerly applied in weather prediction already in sixtieth, its boom in natural science came only after millennium (Šnorek, 2002; Guo et al., 2006; Wang et al., 2011). In fact AI represent very simplified, but selectively and thus efficiently acting models of brain or certain abstract cognitive activities, i.e. AM. As well known special forms of AI like neural networks (Šnorek, 2002) or Gaussian fuzzy logics (see Wang's theorem; Wang, 1992; Jura, 2003) sufficiently imitate almost any mathematical function defined on a compact set. It is a question, whether we can restrict some more communicable description of the functions generated by AI. This means the possibility of converting these functions into the corresponding schemes or scenes related to TE, HMT or consistent differential equations or formulas.

9. Examples of MH Forming Recent Theories Important for Natural Science

The analogy (i.e. Mp) between sound and light evoked the idea of the wave substance of light pronounced by C. Huygens (**Table 3**). This idea was then generalized to all electromagnetic waves by J.C. Maxwell (Ado et al., 1981; **Table 3**). It is a historical question, whether these textbooks interpretations inspired analogous derivation of **Schrödinger equation**, representing fundamental MH in recent structural chemistry More precisely, this means the substitution of the wave length in acoustic (i.e. sound-related) equation by the wave-length-determining right part of De Broglie formula (Brdička & Dvořák, 1977; see also Schrödinger in **Table 3**).

Turing (1952) was the first scientist, who tried to model non-mechanistic **chaos** using MH (cf. Maxwell J.C. in **Table 3**). His model concerned cell differentiation and comprised diffusion phenomena. In the end of the same decade, the first messages about **deterministic** (non-mechanistic) **chaos** appeared and were lately strongly expressed by the equation of Lorenz (1963) investigating weather (see **Table 3**). Deterministic chaos was continuously substituted as physical paradigm (see below) by its more precise followers after more than twenty years, i.e. by (i) **quantum chaos** (Steeb, 1985) and (ii) **generalized** diffusion specified for understanding certain events in embryogenesis and cell differentiation (Murase & Matsuo, 1991) similarly to diffusion-based Turing's considerations. As in case of generalized diffusion, quantum chaotic events are accompanied by diffusion. We can speak about "quantum smoothened" description, which lead to the loss of singularities typical for deterministic chaos (Altland & Haake, 2012). Consequently, a question arises how the new chaotic MH influence fashionable philosophical opinions reflecting or supported by deterministic chaos (see also **Table 3**).

String theory is a unique theory which perhaps unifies four types of known natural forces (i.e. electromagnetic, weak or strong nuclear attraction and gravity) to one concept of association and dissociation of different strings substituting point particles in Euclidian space (Long et al., 2003; Trevors, 2006). String theory was formulated in sixtieth (**Table 3**). One time-related and ten space-related dimensions were proposed for our current space when assuming necessary external dimensions (Damour et al., 2002; Maartens, 2004). In addition, twenty six space-related dimensions were designed for bosons due to additional considerations concerning string orientations (Nojiri, 1987; Clavelli & Jones, 1989; Becker, & Schwarz 2007; Park & Sugimoto, 2020). In agreement with quantum and string theory, certain minimal possible lengths were restricted as Planck length ($1.616 * 10^{-35}$ m) and string lengths (in the range 10^{-34} - 10^{-33} m), respectively (Amelino-Camelia, 2001; El Naschie, 2004; Burgess & Quevedo, 2007). These limits thus constitute interesting weight maximum for photons as separated energy transferring or transforming particles. This maximum corresponds to the spherical drops of water with the diameter 0.16 - 0.64 mm. Deciding majority of the other energy transforming and energetically unified units, i.e. cells, achieves lower sizes than these drops (Kubrycht & Sigler, unpublished data). The sizes of protozoans and different types of somatic eukaryotic cells forming multicellular organisms (**TSEC**) are even closer to the sizes of the model drops. The considerable part of the sizes related to vertebrate TSEC then falls into the interval limited by the values about ten times lower than corresponds to the drop-related interval. This raises the question whether the described size relationships are somehow significant.

Eight levels of **biothermodynamic descriptions** (expressed by means of MH), whose complexity increased with decreased physical volumes, were known even in the seventies (Dvořák et al., 1982). Besides the most complicated thermodynamic description of the processes in the smallest volumes, **Liouville equation** allowed also the simulation of electron paramagnetic resonance (Balescu, 1975; Dvořák et al., 1982; Misra, 2007). This equation was even generalized in this century (Tarasov, 2004; Keller et al., 2011). Moreover, biothermodynamics and reaction kinetics participated in the solution of **philosophically important questions**, i.e. searches for (i) principles describing departures from thermodynamic equilibrium such as origin of life (Prigogine, 1978; Attard, 2006; Hordijk, 2017), (ii) general thermodynamic criterion of evolution (Dvořák et al., 1982; Hochberg & Ribo, 2021) and (iii) rational general description of biological self-organization (Killingback & Doebeli, 1998; Karl, 2012; Busseniers et al., 2021).

10. Conclusion

In spite of certain progress, some unsolved questions and problems appear to be important for further investigation of the commented theme. This concerns (i) better identification of TTM, i.e. clarification of detailed specifications or definitions, correct usage of the terms and knowledge about history and prehistory of TTM, (ii) learning or teaching abilities to form TTM representatives, (iii) reasonable and correct usage of different TTM in experimental science, (iv) importance of dualities for formation of new TTM representatives and (v) better understanding interrelationships between individual TTM (for approximate summarizing scheme see **Figure 1**).

Due to importance of the introduced five points, **several the corresponding comments associated also with this paper** have to be introduced. As regards the preceding point (i), unspecific usage of the term TE in nineteenth century was commented and some attempts to specify TE were described in chapter 2. Since historical reconstruction represents important procedure in the corresponding investigation, the deduced abstract consensual (typical and ideal) objects appear to be serious at least as entities defining standard subset of TE denoted as consensual abstract-object-containing TE (**coTE**). The classifications including coTE and non-coTE can be thus considered as independent dimension additional to the dimensions described in the corresponding section of **Table 1**. For possible competitive terms denominating some non-coTE as non-TE TE-like entities see section "Specificity" in **Table 1**. The **formation of new TTM** representatives or adequate usage of existing TTM (cf. the pre-selected points ii, iii and iv) depends on correct understanding to investigated process and formalization. This comprises not only knowledge about TTM and the corresponding topical systemic relationships, but also record or outline of possible critically re-evaluated **relevant abstractions**, and sometimes also similarities, patterns or simulations (cf. chapters 2, 3, 4 and 7). To develop, **clarify or better present** opinions in both experimental and theoretical science, illustrative TE, reverse abstraction and different data representations can be suitable in agreement with chapters 2, 4 or 7 (cf. the points ii and iii). **Dualism in description of natural processes** (cf. the point iv) represent important stimulus to look for unifying theoretical solutions enabling better understanding to observed events (cf. chapter 7 or **Tables 2** and **Tables 3**). In my opinion, the proposed group of inter-growing dualities (see examples displayed in **Table 2**) could constitute important form of dualities occurring in biology. This however needs further discussions philosophical and biological aspects of this proposal. In accordance with **Figure 1** corresponding to the pre-selected point v, certain **TTM can sometimes cooperate** or even step-by-step participate in grading searches for solutions.

Though considerable part of the recent theoretical papers comprise usage of **computer assisted AM**, certain TTM without or before computer applications or even without preformed systemic analysis still exist (chapters 2-4, 8 and 9). These papers include TE as well as some HMT, MH and approximate AM, which indicates continuing possibility of **old conventional theoretical work**. Recent **trends of computer applications** comprise predictions based on widely-usable quantum computers (Barrow, 1997), AI (chapters 7 and 8) and perhaps also AI connected with knowledge-based systems. Consequently, it is a question, whether we wait to see novel computer programs markedly helping with formulation of TTM.

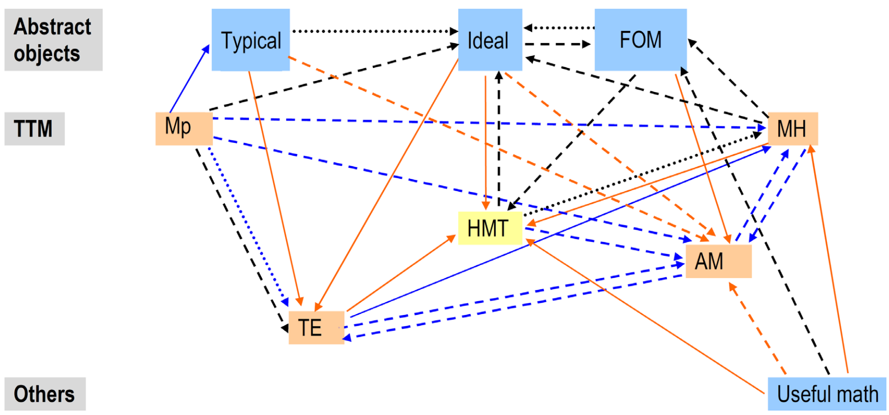

Figure 1. Simplified scheme dealing with the relationships between TTM described here. In addition to separate formation of individual TTM-related representatives, part of these entities participated in formation of the other TTM-related forms during history (cf. **Table 3** and chapters 2,3,4,8 or 9). In this scheme, TE are reduced to the subset of TE containing consensual abstract objects (i.e. coTE) mentioned also in chapter 10. If distinct TE complementary to coTE (i.e. non-coTE) indeed exist, their better specification will enable their correct integration to the proposed scheme. Abbreviations: AM – abstract models; FOM – formalized object models (abstract objects used in object-oriented programming); HMT - hybrids of mathematical hypotheses and thought experiments (more frequently using modified ideal objects; cf. chapter 4); MH – mathematical hypotheses; Mp – metaphors; TE – thought experiments; TTM – types of theoretical methods described in this paper. Colors of lines: black – advisory or specifying relationships; blue - generative interrelationships between TTM subsets indicating via arrows which TTM subset can form the subsequent TTM subset (cf. chapters 2-5 and **Table 3**); orange – components of the pointed types of methods. Forms of lines: dashed – relationships of lower (but still significant) frequency than those represented by full lines; dotted – relationships in question; full – frequent relationships. Proofs: ochre – classical TTM, yellow – more recently proposed TTM.

Since the world of theoretical science is indeed heterogeneous and variously investigated, many theoretically important personalities were not mentioned here. Consequently, I would appreciate, if anybody will substantially complete or correct the above views and opinions.

Acknowledgements

The author thanks his family for a patience and ing Karel Sigler DrSc for the help with processing of English version of the paper.

Conflicts of Interest

The author declares no conflict of interest regarding the publication of this paper.

References

Ado, A. V., Afanasjev, V. G., Afanasjev, V. S., Altman, V. V., Ancyferovová, L. I., Anikejev, N. P., Antipinová, G. S., Arzakaňan, C. G., Asmus, V. F., Baller, E. A., & Zybkovec, V. F. (1981). *Philosophical Dictionary*. Svoboda.

Aguinis, H., Beltran, J. R., Archibold, E. E., Esther, L. J., & Darryl, B. R. (2023). Thought Experiments: Review and Recommendations. *Journal of Organizational Behaviour, 44,* 1-17. https://doi.org/10.1002/job.2658

Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K., & Walter, P. (2008). *Molecular Biology of the Cell* (5th ed.). Garland Science. https://doi.org/10.1201/9780203833445

Ali, A. M., & Kunugi, H. (2021). Propolis, Bee Honey, and Their Components Protect against Coronavirus Disease 2019 (COVID-19): A Review of *in Silico*, *in Vitro*, and Clinical Studies. *Molecules, 26,* Article No. 1232. https://doi.org/10.3390/molecules26051232

Altland, A., & Haake, F. (2012). Quantum Chaos and Effective Thermalization. *Physical Review Letters, 108,* Article ID: 073601. https://doi.org/10.1103/PhysRevLett.108.073601

Altschul, S. F., Madden, T. L., Schäffer, A. A., Zhang, J., Zhang, Z., Miller, W., & Lipman, D. J. (1997). Gapped BLAST and PSI-BLAST: A New Generation of Protein Database Search Programs. *Nucleic Acids Research, 25,* 3389-3402. https://doi.org/10.1093/nar/25.17.3389

Amelino-Camelia, G. (2001). A Phenomenological Description of Space-Time Noise in Quantum Gravity. *Nature, 410,* 1065-1067. https://doi.org/10.1038/35074035

Apertet, Y., Ouerdane, H., Goupil, C., & Lecoeur, P. (2014). Revisiting Feynman's Ratchet with Thermoelectric Transport Theory. *Physical Review E, Statistical, Nonlinear, and Soft Matter Physics, 90,* Article ID: 012113. https://doi.org/10.1103/PhysRevE.90.012113

Arcon, J. P., Turjanski, A. G., Martí, M. A., & Forli, S. (2021). Biased Docking for Protein-Ligand Pose Prediction. *Methods in Molecular Biology, 2266,* 39-72. https://doi.org/10.1007/978-1-0716-1209-5_3

Aristotle (1961). *Prior Analytics*. Czechoslovak Academy of Science Publishing.

Asimov, I. (1994). *Asimov's Chronology of Science and Discovery (Updated and Illustrated)*. HarperCollins Publishers.

Aspect, A. (2017). From Huygens' Waves to Einstein's Photons: Weird Light. *Comptes*

Rendus Physique, 18, 498-503. https://doi.org/10.1016/j.crhy.2017.11.005

Attard, P. (2006). Theory for Non-Equilibrium Statistical Mechanics. *Physical Chemistry Chemical Physics, 8,* 3585-3611. https://doi.org/10.1039/b604284h

Balescu, R. (1975). *Equilibrium and Nonequilibrium Statistical Mechanics*. Wiley.

Barrow, J. D. (1997). *Theories of Everything. The Quest for Ultimate Explanation*. Mladá Fronta.

Becker, M., & Schwarz, J. H. (2007). *String Theory and M-Theory: A Modern Introduction*. Cambridge University Press. https://www.cambridge.org/9780521860697 https://doi.org/10.1017/CBO9780511816086

Bečvář, J. (2012). Archimédés—Life and Work. In Z. Halas (Ed.), *Archimédés* (pp. 1-21). Matfyzpress (Charles University). http://dml.cz/dmlcz/402374

Bergeron, K., Abdi, S., DeCorby, K., Mensah, G., Rempel, B., & Manson, H. (2017). Theories, Models and Frameworks Used in Capacity Building Interventions Relevant to Public Health: A Systematic Review. *BMC Public Health, 17,* Article No. 914. https://doi.org/10.1186/s12889-017-4919-y

Berryman, S. (2022). Ancient Atomism. In E. N. Zalta, & U. Nodelman (Eds.), *The Stanford Encyclopedia of Philosophy (Winter 2022 Edition)*. Stanford University. https://plato.stanford.edu/archives/win2022/entries/atomism-ancient/

Boček, L. (1976). *Tensor Calculus*. Mathematical Seminaries, SNTL.

Bohmer, M. (2012). *Design Patterns in PHP*. Computer Press.

Bolmatov, D., Kinnun, J. J., Katsaras, J., & Lavrentovich, M. O. (2020). Phonon-Mediated Lipid Raft Formation in Biological Membranes. *Chemistry and Physics of Lipids, 232,* Article ID: 104979. https://doi.org/10.1016/j.chemphyslip.2020.104979

Boregowda, S. C., Tiwari, S. N., Chaturvedi, S. K., & Redondo, D. R. (1997). Analysis and Quantification of Mental Stress and Fatigue Using Maxwell Relations from Thermodynamics. *Journal of Human Ergology, 26,* 7-16.

Brdička, R., & Dvořák, J. (1977). *Fundamentals of Physical Chemistry*. Academia.

Buchsteiner, A., Gauss, T., Dante, S., & Dencher, N. A. (2010). Alzheimer's Disease Amyloid-Beta Peptide Analogue Alters the Ps-Dynamics of Phospholipid Membranes. *Biochimica et Biophysica Acta, 1798,* 1969-1976. https://doi.org/10.1016/j.bbamem.2010.06.024

Burge, T. (1979). Individualism and the Mental. *Midwest Studies in Philosophy, 4,* 73-121. https://doi.org/10.1111/j.1475-4975.1979.tb00374.x

Burgess, C., & Quevedo, F. (2007). The Great Cosmic Roller-Coaster Ride. *Scientific American, 297,* 52-59. https://doi.org/10.1038/scientificamerican1107-52

Busseniers, E., Veloz, T., & Heylighen, F. (2021). Goal Directedness, Chemical Organizations, and Cybernetic Mechanisms. *Entropy, 23,* Article No. 1039. https://doi.org/10.3390/e23081039

Calisher, C. H. (2007). Taxonomy: What's in a Name? Doesn't a Rose by Any Other Name Smell as Sweet? *Croatian Medical Journal, 48,* 268-270.

Černík, V. (1972). *Thought Experiment and Production of Ideas*. Pravda.

Černík, V., Farkašová, E., & Viceník, J. (1980). *Theory of Knowledge*. Bratislava, Czechoslovakia, Pravda.

Chapman, R. L., & Andurkar, S. V. (2022). A Review of Natural Products, Their Effects on SARS-CoV-2 and Their Utility as Lead Compounds in the Discovery of Drugs for the Treatment of COVID-19. *Medicinal Chemistry Research, 31,* 40-51. https://doi.org/10.1007/s00044-021-02826-2

Chytil, M. (1984). *Automata and Grammars*. Mathematical Seminaries, SNTL.

Clancey, W. J. (1985). Heuristic Classification. *Artificial Intelligence, 27,* 289-350. https://doi.org/10.1016/0004-3702(85)90016-5

Clark, L. A., & van Vlijmen, H. W. (2008). A Knowledge-Based Forcefield for Protein-Protein Interface Design. *Proteins, 70,* 1540-1550. https://doi.org/10.1002/prot.21694

Clavelli, L., & Jones, S. T. (1989). Finiteness of the Bosonic String in Fewer than 26 Dimensions. *Physical Review D, Particles and Fields, 39,* 3795-3797. https://doi.org/10.1103/PhysRevD.39.3795

Cottet, N., Jezouin, S., Bretheau, L., Campagne-Ibarcq, P., Ficheux, Q., Anders, J., Auffèves, A., Azouit, R., Rouchon, P., & Huard, B. (2017). Observing a Quantum Maxwell Demon at Work. *Proceedings of National Academy of Sciences, USA, 114,* 7561-7564. https://doi.org/10.1073/pnas.1704827114

Damour, T., Henneaux, M., & Nicolai, H. (2002). E10 and a Small Tension Expansion of M Theory. *Physical Review Letters, 89,* Article ID: 221601. https://doi.org/10.1103/PhysRevLett.89.221601

Devkota, P., Mohanty, S. D., & Manda, P. (2022). A Gated Recurrent Unit Based Architecture for Recognizing Ontology Concepts from Biological Literature. *BioData Mining, 15,* Article No. 22. https://doi.org/10.1186/s13040-022-00310-0

Dörner, T., Foster, S. J., Brezinschek, H. P., & Lipsky, P. E. (1998). Analysis of the Targeting of the Hypermutational Machinery and the Impact of Subsequent Selection on the Distribution of Nucleotide Changes in Human VHDJH Rearrangements. *Immunological Reviews, 162,* 161-171. https://doi.org/10.1111/j.1600-065X.1998.tb01439.x

Dunbrack, R. L. Jr. (1999). Comparative Modeling of CASP3 Targets Using PSI-BLAST and SCWRL. *Proteins, Supplement, 3,* 81-87. https://doi.org/10.1002/(SICI)1097-0134(1999)37:3+<81::AID-PROT12>3.0.CO;2-R

Duquette, M. L., Huber, M. D., & Maizels, N. (2007). G-Rich Proto-Oncogenes Are Targeted for Genomic Instability in B-Cell Lymphomas. *Cancer Research, 67,* 2586-2594. https://doi.org/10.1158/0008-5472.CAN-06-2419

Dvořák, I., Maršík, F., & Andrej, L. (1982). *Biothermodynamics*. Academia.

El Naschie, M. S. (2004). A Review of E Infinity Theory and the Mass Spectrum of High Energy Particle Physics. *Chaos, Solitons and Fractals, 19,* 209-236. https://doi.org/10.1016/S0960-0779(03)00278-9

Ermentrout, G. B., & Edelstein-Keshet, L. (1996). Cellular Automata Approaches to Biological Modeling. *Journal of Theoretical Biology, 160,* 97-133. https://doi.org/10.1006/jtbi.1993.1007

Ernst, F. (2015). Thought Experiments in Historiographic Function: Max Weber on Eduard Meyer and the Question of Counterfactuality. *Berichte zur Wissenschaftsgeschichte, 38,* 77-91. https://doi.org/10.1002/bewi.201501702

Evers, A., Gohlke, H., & Klebe, G. (2003). Ligand-Supported Homology Modelling of Protein Binding-Sites Using Knowledge-Based Potentials. *Journal of Molecular Biology, 334,* 327-345. https://doi.org/10.1016/j.jmb.2003.09.032

Ewe, C. K., Sommermann, E. M., Kenchel, J., Flowers, S. E., Maduro, M. F., Joshi, P. M., & Rothman, J. H. (2022). Feedforward Regulatory Logic Controls the Specification-to-Differentiation Transition and Terminal Cell Fate during *Caenorhabditis elegans* Endoderm Development. *Development, 149,* dev200337. https://doi.org/10.1242/dev.200337

Fajkus, B. (1997). *Recent Philosophy and Methodology of Science*. Filosofia.

Falissard, B. (2011). A Thought Experiment Reconciling Neuroscience and Psychoanalysis. *Journal of Physiology, Paris, 105,* 201-206. https://doi.org/10.1016/j.jphysparis.2011.07.007

Felsenstein, J. (1981). Evolutionary Trees from DNA Sequences: A Maximum Likelihood Approach. *Journal of Molecular Evolution, 17,* 368-376. https://doi.org/10.1007/BF01734359

Fenske, D. B., & Jarrell, H. C. (1991). Phosphorus-31 Two-Dimensional Solid-State Exchange NMR. Application to Model Membrane and Biological Systems. *Biophysical Journal, 59,* 55-69. https://doi.org/10.1016/S0006-3495(91)82198-1

Feynman, R. P. (1966). The Development of the Space-Time View of Quantum Electrodynamics. *Science, 153,* 699-708. https://doi.org/10.1126/science.153.3737.699

Fowler, M. (2009). *UML Distilled: A Brief Guide to Standard Object Modeling Language* (3rd ed.). Grada Publishing.

Gamma, E., Helm, R., Johnson, R., & Vlissides, J. (2003). *Design Patterns—Elements of Reusable Object-Oriented Software*. Grada Publishing.

Ganong, W. F. (2005). *Review of Medical Physiology*. Galén.

Gemovic, B., Sumonja, N., Davidovic, R., Perovic, V., & Veljkovic, N. (2019). Mapping of Protein-Potein Interactions: Web-Based Resources for Revealing Interactomes. *Current Medicinal Chemistry, 26,* 3890-3910. https://doi.org/10.2174/0929867325666180214113704

Godzik, A., Skolnick, J., & Kolinski, A. (1993). Regularities Interaction Patterns of Globular Proteins. *Protein Engineering, 6,* 801-810. https://doi.org/10.1093/protein/6.8.801

Green, E. D., Watson, J. D., & Collins, F. S. (2015). Human Genome Project: Twenty-Five Years of Big Biology. *Nature, 526,* 29-31. https://doi.org/10.1038/526029a

Guo, J., Pu, X., Lin, Y., & Leung, H. (2006). Protein Subcellular Localization Based on PSI-BLAST and Machine Learning. *Journal of Bioinformatics and Computational Biology, 4,* 1181-1195. https://doi.org/10.1142/S0219720006002405

Harper, H. A. (1977). *Review of Physiological Chemistry*. Avicenum.

Hatina, J., & Sykes, B. (1999). *Medical Genetics. Problems and Approaches*. Academia.

Hehmeyer, I., & Khan, A. (2007). Islam's Forgotten Contributions to Medical Science. *CMAJ, 176,* 1467-1468. https://doi.org/10.1503/cmaj.061464

Helfrich, W. (1973). Elastic Properties of Lipid Bilayers: Theory and Possible Experiments. *Zeitschrift für Naturforschung C, Journal of Biosciences, 28,* 693-703. https://doi.org/10.1515/znc-1973-11-1209

Heraclitus (2009). *Heraclitus from Fragments DK22B (On-Line Accessible Direct Fragments of Heraclitus)*.

Hirai, M., Komára, R., Takeuchi, K., Sugiyama, M., Kasahara, K., Ohta, N., Farago, B., Stadler, A., & Zaccai, G. (2013). Change of Dynamics of Raft-Model Membrane Induced by Amyloid-β Protein Binding. *The European Physical Journal E, Soft Matter, 36,* 74. https://doi.org/10.1140/epje/i2013-13074-3

Hochberg, D., & Ribó, J. M. (2021). Entropic Analysis of Bistability and the General Evolution Criterion. *Physical Chemistry Chemical Physics, 23,* 14051-14063. https://doi.org/10.1039/D1CP01236C

Horák, J., & Kotyk, A. (1977). *Enzyme Kinetics*. Academia.

Hordijk, W. (2017). Autocatalytic Confusion Clarified. *Journal of Theoretical Biology, 435,* 22-28. https://doi.org/10.1016/j.jtbi.2017.09.003

Hu, W., Begum, N. A., Mondal, S., Stanlie, A., & Honjo, T. (2015). Identification of DNA

Cleavage- and Recombination-Specific hnRNP Cofactors for Activation-Induced Cytidine Deaminase. *Proceedings of the National Academy of Sciences, USA, 112,* 5791-5796. https://doi.org/10.1073/pnas.1506167112

James, C. W., Falcke, H., Huege, T., & Ludwig, M. (2011). General Description of Electromagnetic Radiation Processes Based on Instantaneous Charge Acceleration in "Endpoints". *Physical Review E, Statistical, Nonlinear, and Soft Matter Physics, 84,* Article ID: 056602. https://doi.org/10.1103/PhysRevE.84.056602

Janout, V. (1995). *Fundaments of Epidemiology*. University of Palacky Publishing.

Jerne, N. K. (1984). Idiotypic Networks and Other Preconceived Ideas. *Immunological Reviews, 79,* 5-24. https://doi.org/10.1111/j.1600-065X.1984.tb00484.x

Jerne, N. K. (1985). The Generative Grammar of the Immune System. *EMBO Journal, 4,* 847-852. https://doi.org/10.1002/j.1460-2075.1985.tb03709.x

Jost, J. D., Home, J. P., Amini, J. M., Hanneke, D., Ozeri, R., Langer, C., Bollinger, J. J., Leibfried, D., & Wineland, D. J. (2009). Entangled Mechanical Oscillators. *Nature, 459,* 683-685. https://doi.org/10.1038/nature08006

Jura, P. (2003). *Fundamentals of Fuzzy Logics for Control and Modeling*. VUTIUM.

Kapitza, P. L., & Lifshitz, E. M. (1969). Lev Davydovitch Landau 1908-1968. *Biographical Memoirs of Fellows of the Royal Society, 15,* 140-158. https://doi.org/10.1098/rsbm.1969.0007

Karl, F. (2012). A Free Energy Principle for Biological Systems. *Entropy, 14,* 2100-2121. https://doi.org/10.3390/e14112100

Kashyap, P., Thakur, M., Singh, N., Shikha, D., Kumar, S., Baniwal, P., Yadav, Y. S., Sharma, M., Sridhar, K., Inbaraj, B. S. (2022). *In Silico* Evaluation of Natural Flavonoids as a Potential Inhibitor of Coronavirus Disease. *Molecules, 27,* Article No. 6374. https://doi.org/10.3390/molecules27196374

Kaur, H., & Raghava, G. P. (2004). Prediction of Alpha-Turns in Proteins Using PSI-BLAST Profiles and Secondary Structure Information. *Proteins, 55,* 83-90. https://doi.org/10.1002/prot.10569

Keller, B., Hünenberger, P., & van Gunsteren, W. F. (2011). An Analysis of the Validity of Markov State Models for Emulating the Dynamics of Classical Molecular Systems and Ensembles. *Journal of Chemical Theory and Computation, 7,* 1032-1044. https://doi.org/10.1021/ct200069c

Kessidy, F. C. (1976). *From Myth to Logos*. Pravda.

Killingback, T., & Doebeli, M. (1998). Self-Organized Criticality in Spatial Evolutionary Game Theory. *Journal of Theoretical Biology, 191,* 335-340. https://doi.org/10.1006/jtbi.1997.0602

Kleppner, D., & Jackiw, R. (2000). One Hundred Years of Quantum Physics. *Science, 289,* 893-898. https://doi.org/10.1126/science.289.5481.893

Klíč, A., Volka, K., & Dubcová, M. (2012). *Fourier's Transformation with Examples from Infrared Spectroscopy*. UCT Publishing. https://doi.org/10.1016/j.imlet.2014.09.014

Kobayashi, Y., Ito, Y., Ostapenko, V. V., Sakai, M., Matsushita, N., Imai, K., Shimizu, K., Aruga, A., & Tanigawa, K. (2014). Fever-Range Whole-Body Heat Treatment Stimulates Antigen-Specific T-cell Responses in Humans. *Immunological Letters, 162,* 256-261.

Kokowski, M. (2006). Nicholas Copernicus in Focus of Interdisciplinary Research: An Outline of Main Results. *Organon, 35,* 73-84. https://www.researchgate.net/publication/263734448

Kolář, J. (2009). *Theoretical Informatics*. CTU Publishing.

Krauzlis, R. J., Wang, L., Yu, G., & Katz, L. N. (2023). What Is Attention? Wiley Interdisciplinary Reviews. *Cognitive Science, 14,* e1570. https://doi.org/10.1002/wcs.1570

Kubrycht, J. (1985). *Thought Experiment in Biology. Selected Philosophical Articles of PhD Students Written at the School Year 1983/1984* (pp. 42-49). Czechoslovak Academy of Sciences.

Kubrycht, J., & Novotná, J. (2014). Sequence-Based Prediction of Linear Autoepitopes Involved in Pathogenesis of IPAH and the Corresponding Organism Sources of Molecular Mimicry. *International Journal of Bioinformatics Research and Applications, 10,* 587-612. https://doi.org/10.1504/IJBRA.2014.065244

Kubrycht, J., & Sigler, K. (2020). Conserved Immunoglobulin Domain Similarities of Higher Plant Proteins. *Computational Molecular Bioscience, 10,* 12-44. https://doi.org/10.4236/cmb.2020.101002

Kubrycht, J., Sigler, K., & Souček, P. (2012). Virtual Interactomics of Proteins from Biochemical Standpoint. *Molecular Biology International, 2012,* Article ID: 976385. https://doi.org/10.1155/2012/976385

Kubrycht, J., Sigler, K., Ruzicka, M., Soucek, P., Borecký, J., & Jezek, P. (2006). Ancient Phylogenetic Beginnings of Immunoglobulin Hypermutation. *Journal of Molecular Evolution, 63,* 691-706. https://doi.org/10.1007/s00239-006-0051-9

Kubrycht, J., Sigler, K., Souček, P., & Hudeček, J. (2013). Structures Composing Protein Domains. *Biochimie, 95,* 1511-1524. https://doi.org/10.1016/j.biochi.2013.04.001

Kubrycht, J., Sigler, K., Souček, P., & Hudeček, J. (2016). Antibody-Like Phosphorylation Sites in Focus of Statistically Based Bilingual Approach. *Computational Molecular Bioscience, 6,* 1-22. https://doi.org/10.4236/cmb.2016.61001

Kugler, F. B. (2018). Counting Feynman Diagrams via Many-Body Relations. *Physical Review E, Statistical, Nonlinear, and Soft Matter Physics, 98,* Article ID: 023303. https://doi.org/10.1103/PhysRevE.98.023303

Kuhn, T. S. (1962). *The Structure of Scientific Revolutions*. University of Chicago Press.

Lakatos, I. (1970). History of Science and Its Rational Reconstructions. In *Proceedings of the Biennial Meeting of the Philosophy of Science Association* (pp. 91-136). Cambridge University Press. https://doi.org/10.1086/psaprocbienmeetp.1970.495757

Lakatos, I. (1976). A Renaissance of Empiricism in the Recent Philosophy of Mathematics. *British Journal for the Philosophy of Science, 27,* 201-223. http://bjps.oxfordjournals.org https://doi.org/10.1093/bjps/27.3.201

Lakhani, B., Thayer, K. M., Hingorani, M. M., & Beveridge, D. L. (2017). Evolutionary Covariance Combined with Molecular Dynamics Predicts a Framework for Allostery in the MutS DNA Mismatch Repair Protein. *The Journal of Physical Chemistry B, 121,* 2049-2061. https://doi.org/10.1021/acs.jpcb.6b11976

Landau, L. D., & Lifshitz, E. M. (1973). *Theoretical Physics. II Theory of Field*. Nauka.

Landmann, S., Preuss, N., & Behn, U. (2017). Self-Tolerance and Autoimmunity in a Minimal Model of the Idiotypic Network. *Journal of Theoretical Biology, 426,* 17-39. https://doi.org/10.1016/j.jtbi.2017.05.004

Laozi (1997). *Tao Te Tiang*. DharmaGaia.

Larsson, J. K., Wadströmer, N., Hermanson, O., Lendahl, U., & Forchheimer, R. (2011). Modelling Cell Lineage Using a Meta-Boolean Tree Model with a Relation to Gene Regulatory Networks. *Journal of Theoretical Biology, 268,* 62-76. https://doi.org/10.1016/j.jtbi.2010.10.003

Lehner, C., & Wendt, H. (2017). Mechanics in the Querelle des Anciens et des Modernes. *Isis, 108,* 26-39. https://doi.org/10.1086/691412

Lepš, J., & Šmilauer, P. (2016). *Biostatistics*. Episteme.

Lewicka, M., Henrykowska, G., Zawadzka, M., Rutkowski, M., Pacholski, K., & Buczyński, A. (2017). Impact of Electromagnetic Radiation Emitted by Monitors on Changes in the Cellular Membrane Structure and Protective Antioxidant Effect of Vitamin A—*In Vitro* Study. *International Journal of Occupational Medicine and Environmental Health, 30,* 695-703. https://doi.org/10.13075/ijomeh.1896.00851

Long, J. C., Chan, H. W., Churnside, A. B., Gulbis, E. A., Varney, M. C., & Price, J. C. (2003). Upper Limits to Submillimetre-Range Forces from Extra Space-Time dimensions. *Nature, 421,* 922-955. https://doi.org/10.1038/nature01432

Lorenz, E. N. (1963). Deterministic Nonperiodic Flow. *Journal of the Atmospheric Science, 20,* 130-141. https://doi.org/10.1175/1520-0469(1963)020<0130:DNF>2.0.CO;2

Maartens, R. (2004). Brane-World Gravity. *Living Reviews in Relativity, 7,* Article No. 7. https://doi.org/10.12942/lrr-2004-7

Mace, T. A., Zhong, L., Kilpatrick, C., Zynda, E., Lee, C. T., Capitano, M., Minderman, H., & Repasky, E. A. (2011). Differentiation of CD8+ T Cells into Effector Cells Is Enhanced by Physiological Range Hyperthermia. *Journal of Leukocyte Biology, 90,* 951-962. https://doi.org/10.1189/jlb.0511229

Machamer, P., & Miller, D. M. (2021). Galileo Galilei. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy (Summer 2021 Edition)*. Stanford University. https://plato.stanford.edu/archives/sum2021/entries/galileo/

Major, L. & Sobotka, M. (1977). *Worldview Significance of Descartes' Philosophy*. Charles University.

Martin, C. (2023). Histories of Medieval Plague in Renaissance Italy. *Journal of the History of Medicine and Allied Sciences, 78,* 131-148. https://doi.org/10.1093/jhmas/jrad001

Martins, R. A. (2003). Resistance to the Discovery of Electromagnetism: Ørsted and the Symmetry of the Magnetic Field. In F. Bevilacqua, & E. Giannetto (Eds.), *Volta and the History of Electricity* (pp. 245-265). Editore Ulrico Hoepli.

Marusic, I., & Broomhall, S. (2021). Leonardo da Vinci and Fluid Mechanics. *Annual Review of Fluid Mechanics, 53,* 1-25. https://doi.org/10.1146/annurev-fluid-022620-122816

Míček, L. (1981). *Thought Experiment*. Ph.D. Theses, Comenius University.

Michaelis, L., Menten, M. L., Johnson, K. A., & Goody, R. S. (2011). The Original Michaelis Constant: Translation of the 1913 Michaelis-Menten Paper. *Biochemistry, 50,* 8264-8269. https://doi.org/10.1021/bi201284u

Misra, S. K. (2007). Simulation of Slow-Motion CW EPR Spectrum Using Stochastic Liouville Equation for an Electron Spin Coupled to Two Nuclei with Arbitrary Spins: Matrix Elements of the Liouville Superoperator. *Journal of Magnetic Resonance (San Diego, Calif.: 1997), 189,* 59-77. https://doi.org/10.1016/j.jmr.2007.08.004

Möller, R., & Schenck, W. (2008). Bootstrapping Cognition from Behavior—A Computerized Thought Experiment. *Cognitive Science, 32,* 504-542. https://doi.org/10.1080/03640210802035241

Mulliken, R. S. (1967). Spectroscopy, Molecular Orbitals, and Chemical Bonding. *Science, 157,* 13-24. https://doi.org/10.1126/science.157.3784.13

Murase, M., & Matsuo, M. (1991). Mathematical Modeling for the Aging Process: Normal, Abnormal and Self-Terminating Phenomena in Spatio-Temporal Organization. *Mechanisms of Ageing and Development, 60,* 99-112. https://doi.org/10.1016/0047-6374(91)90113-E

Newell, A. (1982). The Knowledge Level. *Artificial Intelligence, 18,* 87-127. https://doi.org/10.1016/0004-3702(82)90012-1

Nilsen, P. (2015). Making Sense of Implementation Theories, Models and Frameworks. *Implementation Science, 10,* Article No. 53. https://doi.org/10.1186/s13012-015-0242-0

Nojiri, S. (1987). Heterotic Strings from the Bosonic String in 26 Dimensions. *Physical Review D, 35,* 2466-2473. https://doi.org/10.1103/PhysRevD.35.2466

Odales, J., Guzman Valle, J., Martínez-Cortés, F., & Manoutcharian, K. (2020). Immunogenic Properties of Immunoglobulin Superfamily Members within Complex Biological Networks. *Cellular Immunology, 358,* Article ID: 104235. https://doi.org/10.1016/j.cellimm.2020.104235

Oussar, Y., & Dreyfus, G. (2001). How to Be a Gray Box: Dynamic Semi-Physical Modeling. *Neural Networks, 14,* 1161-1172. https://doi.org/10.1016/S0893-6080(01)00096-X

Park, J. H., & Sugimoto, S. (2020). String Theory and Non-Riemannian Geometry. *Physical Review Letters, 125,* Article ID: 211601. https://doi.org/10.1103/PhysRevLett.125.211601

Philippe, H. (1993). MUST, a Computer Package of Management Utilities for Sequences and Trees. *Nucleic Acids Research, 21,* 5264-5272. https://doi.org/10.1093/nar/21.22.5264

Prigogine, I. (1978). Time, Structure, and Fluctuations. *Science, 201,* 777-785. https://doi.org/10.1126/science.201.4358.777

Pross, H. F., & Maroun, J. A. (1984). The Standardization of NK Cell Assays for Use in Studies of Biological Response Modifiers. *Journal of Immunological Methods, 68,* 235-249. https://doi.org/10.1016/0022-1759(84)90154-6

Rahman, M. M., Islam, M. R., Akash, S., Mim, S. A., Rahaman, M. S., Emran, T. B., Akkol, E. K., Sharma, R., Alhumaydhi, F. A., Sweilam, S. H., Hossain, M. E., Ray, T. K., Sultana, S., Ahmed, M., Sobarzo-Sánchez, E., & Wilairatana, P. (2022). *In Silico* Investigation and Potential Therapeutic Approaches of Natural Products for COVID-19: Computer-Aided Drug Design Perspective. *Frontiers in Cellular and Infection Microbiology, 12,* Article ID: 929430. https://doi.org/10.3389/fcimb.2022.929430

Richardson, P. L. (2019). Leonardo da Vinci's Discovery of the Dynamics Soaring by Birds in Wind Shear. *Notes and Records, 73,* 285-301. https://doi.org/10.1098/rsnr.2018.0024

Rickles, D. (2014). *A Brief History of String Theory: From Dual Models to M-Theory.* Springer Verlag. https://doi.org/10.1007/978-3-642-45128-7

Roberts, S. A., Gordenin, D. A. (2014). Hypermutation in Human Cancer Genomes: Footprints and Mechanisms. *Nature Reviews on Cancer, 14,* 786-800. https://doi.org/10.1038/nrc3816

Rodionov, M. A., & Johnson, M. S. (1994). Residue-Residue Contact Substitution Probabilities Derived from Aligned Three-Dimensional Structures and the Identification of Common Folds. *Protein Science, 3,* 2366-2377. https://doi.org/10.1002/pro.5560031221

Rogozin, I. B., & Kolchanov, N. A. (1992). Somatic Hypermutagenesis in Immunoglobulin Genes. II. Influence of Neighbouring Base Sequences on Mutagenesis. *Biochimica Biophysica Acta, 1171,* 11-18. https://doi.org/10.1016/0167-4781(92)90134-L

Saitou, N., & Nei, M. (1987). The Neighbor-Joining Method: A New Method for Reconstructing Phylogenetic Trees. *Molecular Biology and Evolution, 4,* 406-425.

Sanapalli, B. K. R., Yele, V., Baldaniya, L., & Karri, V. V. S. R. (2022). Identification of Novel Protein Kinase C-βII Inhibitors: Virtual Screening, Molecular Docking and Molecular Dynamics Simulation Studies. *Journal of Molecular Modeling, 28,* 117. https://doi.org/10.1007/s00894-022-05104-z

Sarbaz, Y., & Pourakbari, H. (2016). A Review of Presented Mathematical Models in Parkinson's Disease: Black- and Gray-Box Models. *Medical & Biological Engineering & Computing, 54,* 855-868. https://doi.org/10.1007/s11517-015-1401-9

Scott, T. C. (2022). From Modified Newtonian Dynamics to Superfluid Vacuum Theory. *Entropy (Basel), 25,* Article No. 12. https://doi.org/10.3390/e25010012

Shilova, O. N., Tsyba, D. L., & Shilov, E. S. (2022). Mutagenic Activity of AID/APOBEC Deaminases in Antiviral Defense and Carcinogenesis. *Molecular Biology, 56,* 46-58. https://doi.org/10.1134/S002689332201006X

Shoja, M. M., Agutter, P. S., Loukas, M., Benninger, B., Shokouhi, G., Namdar, H., Ghabili, K., Khalili, M., & Tubbs, R. S. (2013). Leonardo da Vinci's Studies of the Heart. *International Journal of Cardiology, 167,* 1126-1133. https://doi.org/10.1016/j.ijcard.2012.09.078

Singer, S. J., & Nicolson, G. L. (1972). The Fluid Mosaic Model of the Structure of Cell membranes. *Science, 175,* 720-731. https://doi.org/10.1126/science.175.4023.720

Smith, J. M., & Szathmary, E. (1995). *The Major Transitions in Evolution*. W. H. Freeman and Company Limited.

Šnorek, M. (2002). *Neural Networks and Neuro-Computers*. CTU Publishing.

Šolcová, A. (2017). *Chapters from History of Mathematics and Informatics*. CTU Publishing.

Sourdis, J., & Nei, M. (1988). Relative Efficiencies of the Maximum Parsimony and Distance-Matrix Methods in Obtaining the Correct Phylogenetic Tree. *Molecular Biology and Evolution, 5,* 298-311.

Stableford, B. (2003). Science Fiction before the Genre. In E. James, & F. Mendlesohn (Eds.), *The Cambridge Companion to Science Fiction* (pp. 15-31). Cambridge University Press. https://doi.org/10.1017/CCOL0521816262.002

Stachová, J. (1993). Metaphor, Intuition, Science. In J. Stachová, & J. Nosek (Eds.), *Intuition in Science and Philosophy* (pp. 299-308). Philosophical Institute of CAS.

Standley, D. M., Yamashita, R., Kinjo, A. R., Toh, H., & Nakamura, H. (2010). SeSAW: Balancing Sequence and Structural Information in Protein Functional Mapping. *Bioinformatics, 26,* 1258-1259. https://doi.org/10.1093/bioinformatics/btq116

Štecha, J. (2003). *Theory of Dynamical Systems*. CTU Publishing.

Steeb, W., Villet, C. M., & Kunick, A. (1985). Quantum Chaos and Two Exactly Solvable Second-Quantized Models. *Physical Review A, General Physics, 32,* 1232-1234. https://doi.org/10.1103/PhysRevA.32.1232

Steele, J. (2019). Explaining Babylonian Astronomy. *Isis, 110,* 292-295. https://doi.org/10.1086/703532

Stutz, A. J. (2014). Modeling the Pre-Industrial Roots of Modern Super-Exponential Population Growth. *PLOS ONE, 9,* e105291. https://doi.org/10.1371/journal.pone.0105291

Tarasov, V. E. (2004). Fractional Generalization of Liouville Equations. *Chaos, 14,* 123-127. https://doi.org/10.1063/1.1633491

Tarkhov, A. E., Alla, R., Ayyadevara, S., Pyatnitskiy, M., Menshikov, L. I., Shmookler Reis, R. J., & Fedichev, P. O. (2019). A Universal Transcriptomic Signature of Age Reveals the Temporal Scaling of *Caenorhabditis elegans* Aging Trajectories. *Scientific*

Reports, 9, Article No. 7368. https://doi.org/10.1038/s41598-019-43075-z

Tateno, Y., Nei, M., & Tajima, F. (1982). Accuracy of Estimated Phylogenetic Trees from Molecular Data. I. Distantly Related Species. *Journal of Molecular Evolution, 18,* 387-404. https://doi.org/10.1007/BF01840887

Terayama, K., Sumita, M., Tamura, R., & Tsuda, K. (2021). Black-Box Optimization for Automated Discovery. *Accounts of Chemical Research, 54,* 1334-1346. https://doi.org/10.1021/acs.accounts.0c00713

Thorvaldsen, S. (2010). Early Numerical Analysis in Kepler's New Astronomy. *Science in Context, 23,* 39-63. https://doi.org/10.1017/S0269889709990238

Toigo, L., Dos Santos Teodoro, E. I., Guidi, A. C., Gancedo, N. C., Petruco, M. V., Melo, E. B., Tonin, F. S., Fernandez-Llimos, F., Chierrito, D., de Mello, J. C. P., de Medeiros Araújo, D. C., & Sanches, A. C. C. (2023). Flavonoid as Possible Therapeutic Targets against COVID-19: A Scoping Review of *in Silico* Studies. *Daru, 31,* 51-68. https://doi.org/10.1007/s40199-023-00461-3

Tomilin, K. A. (1999). Natural Systems of Units. To the Centenary Anniversary of the Planck System. In *Proceedings of the XXII Workshop on High Energy Physics and Field Theory* (pp. 287-296). IHEP. http://web.ihep.su/library/pubs/tconf99/ps/tomil.pdf

Trevors, J. T. (2006). The Big Bang, Superstring Theory and the Origin of Life on the Earth. *Theory in Biosciences, 124,* 403-412. https://doi.org/10.1016/j.thbio.2005.04.002

Turing, A. (1952). The Chemical Basis of Morphogenesis. *Philosophical Transactions of the Royal Society of London Series B, Biological Sciences, 237,* 37-72. https://doi.org/10.1098/rstb.1952.0012

Unčovský, L. (1980). *Stochastic Models of Operational Analysis*. Alfa.

Van Dyck, M., & Malara, I. (2019). Renaissance Concept of Impetus. In M. Sgarbi (Ed.), *Encyclopedia of Renaissance Philosophy* (pp. 1-6). Springer. https://doi.org/10.1007/978-3-319-02848-4_261-1

Wang, C., Liu, Y., & Cao, J.-M. (2014). G Protein-Coupled Receptors: Extranuclear Mediators for the Non-Genomic Actions of Steroids. *International Journal of Molecular Sciences, 15,* 15412-15425. https://doi.org/10.3390/ijms150915412

Wang, L.-X. (1992). Fuzzy Systems Are Universal Approximations. In *Proceedings of IEEE International Conference on Fuzzy Systems* (pp. 1163-1170). IEEE.

Wang, Y. C., Wang, Y., Yang, Z. X., & Deng, N. Y. (2011). Support Vector Machine Prediction of Enzyme Function with Conjoint Triad Feature and Hierarchical Context. *BMC Systems Biology, 5,* S6. https://doi.org/10.1186/1752-0509-5-S1-S6

Watson, J. D., & Crick, F. H. (1953). Molecular Structure of Nucleic Acids; a Structure for Deoxyribose Nucleic Acid. *Nature, 171,* 737-738. https://doi.org/10.1038/171737a0

Wielinga, B., & Schreiber, G. (1990). KADS: Model Based KBS Development. In *GWAI-90 14th German Workshop on Artificial Intelligence* (pp. 322-323). Springer-Verlag. https://doi.org/10.1007/978-3-642-76071-6_36

Wildberg, C. (2021). John Philoponus. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy (Winter 2021 Edition)*. Stanford University. https://plato.stanford.edu/archives/win2021/entries/philoponus/

Wilson, P., Liu, Y. J., Banchereau, J., Capra, J. D., & Pascual, V. (1998). Amino Acid Insertions and Deletions Contribute to Diversify the Human Ig Repertoire. *Immunological Reviews, 162,* 143-151. https://doi.org/10.1111/j.1600-065X.1998.tb01437.x

Wiltsche, H. (2019). The Forever War: Understanding, Science Fiction, and Thought Experiments. *Synthese, 230,* 1-24.

Witt-Hansen, J. (1976). H. C. Örsted, Immanuel Kant, and the Thought Experiment. *Danish Yearbook of Philosophy, 13,* 48-65. https://doi.org/10.1163/24689300-01301004

Yamamoto, K., Wang, X. X., Tamaki, M., & Suzuki, K. (2019). The Second Offshore Production of Methane Hydrate in the Nankai Trough and Gas Production Behavior from a Heterogeneous Methane Hydrate Reservoir. *RSC Advances, 9,* 25987-26013. https://doi.org/10.1039/C9RA00755E

Yeates, L. B. (2004). *Thought Experimentation: A Cognitive Approach*. Ph.D. Thesis, University of New South Wales.

Zeng, X., & Li, S. (2011). Multiscale Modeling and Simulation of Soft Adhesion and Contact of Stem Cells. *Journal of the Mechanical Behavior of Biomedical Materials, 4,* 180-189. https://doi.org/10.1016/j.jmbbm.2010.06.002

Zhu, K., Day, T., Warshaviak, D., Murrett, C., Friesner, R., & Pearlman, D. (2014). Antibody Structure Determination Using a Combination of Homology Modeling, Energy-Based Refinement, and Loop Prediction. *Proteins, 82,* 1646-1655. https://doi.org/10.1002/prot.24551

Zynda, E. R., Grimm, M. J., Yuan, M., Zhong, L., Mace, T. A., Capitano, M., Ostberg, J. R., Lee, K. P., Pralle, A., & Repasky, E. A. (2015). A Role for the Thermal Environment in Defining Co-Stimulation Requirements for CD4(+) T Cell Activation. *Cell Cycle, 14,* 2340-2354. https://doi.org/10.1080/15384101.2015.1049782