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Editorial

Turing Learning Machines

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Alan Mathison Turing was born in London on June 23rd, 1912. In 1934, he graduated with top marks from King's College, University of Cambridge, and in 1936, he obtained his Ph.D. from Princeton University, located in New Jersey, USA. In 1940, he worked at Bletchley Park for the Communications Department, using the Colossus machine to decipher Nazi codes. After the war, he moved to the National Physical Laboratory in Teddington, near London. In 1947, he returned to the University of Cambridge, and in 1951, he went to the University of Manchester.

Turing is one of the founding fathers of computer science. He achieved theoretical results that profoundly influenced its development, including technology. He was the first to address the theme of artificial thought, launching a challenge called the "Turing test", which only recently has been passed by machines. The test is a conceptual experiment based on the "imitation game", very popular in his time. In Turing's version, a person asks questions to two other people (a man and a woman) trying to discover who the woman is and who is the man. Turing modified this game by replacing the woman (or man) with a machine and asking the questioner to find out who is the machine. Turing believed that if a machine could deceive a human, then the machine would be capable of thinking. Many have criticized this reasoning, stating that the only result of the experiment would be the phenomenological demonstration of the ability to deceive but not the ontological ability to think.

His 1950 paper, *Computing Machinery and Intelligence*, published in the journal *Mind*, begins with the famous question «*Can machines think?*» and with the proposal, provocative at that time, to use a simple test to answer. The article, very detailed and complex, contains a meticulous enumeration of potential opposing positions to his proposal. It ranges from the theological objection «*Thinking is a function of man's immortal soul*» to the mathematical one, to the one related to consciousness, up to extrasensory perception. Reading again his reasoning, one never ceases to discover details, insights, allusions.

The perhaps lesser-known part of the article is dedicated to «*Learning Machines*». In the last two years, the successes of artificial intelligence have been made possible by a particular technique called *Machine Learning*. Despite the linguistic similarity, the two concepts have a significantly different meaning. In the former, Turing describes the procedure to follow for the realization of a learning machine, and then to use for his test. The latter is a field of computer science developing computational models that can adapt with experience, which have recently demonstrated their enormous power and effectiveness.

After formulating his idea, to build a machine capable of imitating the human mind, Turing analyzes in detail the operational steps to realize such a machine. He starts from an observation that Lady Lovelace reports in her account of Charles Babbage's analytical machine «*The analytical machine has no pretentions to originate anything, it can do whatever we know how to order it to perform*», but he adds, perhaps unintentionally, a small but significant variation «*The machine can* only *do what we know how to order it to do it*». The following is an exciting crescendo of passages, in which he first hypothesizes the realization of a "child machine" «*Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which simulates the child's?*» and then explains in minute details the learning process to which such a machine must be subjected. He concludes with a dry and opti-

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mistic statement «*We may hope that machines will eventually compete with men in all purely intellectual fields*». Moreover, he qualifies this event as something positive, even beneficial for humanity, using the verb "hope". In subsequent years, other scientists have taken diametrically opposed positions, believing that an artificial intelligence capable of performing "all" human intellectual activities would be a serious threat to humanity. This is the much discussed and controversial artificial general intelligence (*AGI*).

What is striking in the analysis of the construction process of his thinking machine are the numerous themes that have then revealed their importance in the debate on the opportunities and risks of artificial intelligence. Turing shows to have a staggering vision of the future, based on a world, that of the Fifties, in which there were few examples of electronic computers, with very limited computational capabilities. He prescribes that the child machine should not have a physicality «*It will not, for instance, be provided with legs, so that it could not be asked to go out and fill the coal scuttle. Possibly it might not have eyes*» but neither emotion «*These definitions do not presuppose any feelings on the part of the machine*». He identifies the essential role of randomness «*It is probably wise to include a random element in the learning machine*», looking forward its use in generative artificial intelligence systems. He poses the problem of explainability «*Its teacher will often be ignorant of what happens inside it*», anticipating an intense and current research strand that does not want to treat artificial intelligence systems as "black boxes", whose contents are inaccessible, but seeks to understand how they work. But what is striking is the idea of treating intelligence as an emergent ability. His words are clear and unequivocal «*Intelligent behaviour presumably consists in a departure from the completely disciplined behaviour involved in computation*» and lapidary «*It will not give rise to random behavior, or to pointless repetitive cycles*». Recent advances in generative artificial intelligence are bringing down the hypothesis that they are only "stochastic parrots", based on chance. At least from a phenomenological point of view, some experiments have instead demonstrated in these systems the existence of "sparks of intelligence".

At the end of his article, Turing wonders which goals thinking machines might achieve by the end of the twentieth century. He lists two: the game of chess and the mastery of the English language, achieved in recent years. Strangely, however, he connects the last goal, mastery of the English language, to something he had initially excluded, the physicality of the child machine. His words are clear «*It is best to provide the machine with the best sense organs that money can buy*» and anticipate an entire research strand, robotics, which has among its objectives precisely that of building artificial entities capable of interacting with the environment, through appropriate "sensory organs".

The sentence that closes his article is a solemn declaration of trust and optimism «*We can only see a short distance ahead, but we can see plenty there that needs to be done*». His mind saw and lucidly evaluated the great scientific and technological achievements of the 1950s and sensed a future full of challenges not only technological but also conceptual, with significant philosophical and social implications. Unfortunately, he did not get to see his future. On March 31st, 1952, he was arrested and convicted of homosexuality and, as an alternative to prison, accepted chemical castration. Seventy years ago, on June 7th, 1954, at the age of 42, he committed suicide by eating a poisoned apple.

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Feature Articles

Potential Use of Multiple Antisense Oligonucleotide Analogs for Cancer Prevention and Therapy

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Abstract. Antisense oligonucleotide (ASO) analogs have been used to counteract the effects of mutated genes and have been developed as therapeutic agents. Several such formulations have been subjected to clinical trials against cancer and have been passed by the FDA for clinical use. However, cancer is a complex genetic disease in which multiple mutations are known to occur for tumors to develop. Three basic stages have been delineated: 1. *Loss of cell growth control* by both oncogenes and tumor suppressor genes; 2. *Angiogenesis*, the production of capillary growth factors to allow blood supply; 3. *Metastasis* allows cancer cells to invade normal tissue. In principle, using three ASOs to down-regulate the products of the mutated genes controlling these specific processes should be possible and this could be an effective preventive method against cancer. In an alternative approach, genetic analysis of cancer cells using microarrays have shown that cassettes of genes are up- and down-regulated compared to normal tissue. Using this information ASOs could be used to down-regulate mutated genes that are up-regulated. In general ASO analog sequences could be used to target the unique pre-mRNA splice sites of selected genes in order to suppress carcinogenesis *in vitro* in selected cancer cell lines and subsequently *in vivo* in chosen mouse models. Computer programs will be used to calculate doses of a cocktail of ASOs to be administered to individual mice and ultimately patients as their tumor genetic profile changes over time.

Keywords: antisense oligonucleotide, cancer, carcinogenesis suppression, prevention, therapy

INTRODUCTION

Selective molecular recognition is the basis of all therapy and of life itself. The specific binding of a drug molecule to a protein/enzyme active site or the binding of a hormone or a natural product into a receptor are common examples. But the selective recognition by base pairing of a sequence of DNA or RNA bases are an even more stringent basis for selectivity. We propose to exploit this fact by using antisense oligonucleotide (ASO) analogs to attempt to treat or prevent cancer.

As indicated at the conclusion of a historical review of antisense oligo applications,[1] antisense should be a way to tackle complex genetic diseases like cancer. In general, it is known that to enable a tumor to grow, three mutations are required[2]: 1. The suppression of *cell growth control*, i.e. loss of contact inhibition; 2. *Angiogenesis*, production of *growth factors for blood capillaries* that enable tumors to grow; 3. *Metastasis*, the ability *to invade normal tissue*. By using the appropriate oligos against splice sites in pre-mRNAs of the appropriate mutations, it might be possible to prevent cancer from developing. This would, of course, be a major project, requiring:

1. The determination of which splice sites to target in mutations in each stage of cancer development; 2. Carrying out *in vitro* studies on cancer cell lines using a combination of three (or more) oligos. This would require at least seven comparable experiments for each set of oligos and different dose regimens; 3. Eventually, with positive results *in vitro*, to extend these studies to *in vivo* experiments with suitable mouse tumor models.

Although this would be a challenging regimen, it is not without the possibility that by monitoring the genetic profile of a given cancer/tumor, it would be possible to down-regulate the mutated genes that are allowing cells to become cancerous and to prevent tumors from developing and metastasizing. Such an experimental protocol would require both the calculation of suitable proportions in a cocktail of ASO analogs with time and of course, the choice of the best ASO analog based on objective comparative criteria.[3]

The stages of carcinogenesis are more complex than indicated above. *Three main stages* can be delineated: 1. Loss of control of cell growth; 2 Production of capillary growth factors (angiogenesis), and 3. Production of tissue infiltration factors (metastasis). But in fact, each of these main stages can also be further divided into several sub-stages.[2] For example, stage 1, loss of cell growth control, can be initiated by oncogenes and down-regulation by mutation of tumor suppressor genes. Other subsidiary mutations can occur, such as loss of DNA repair mechanisms, mutations to the genes that allow the cells to evade apoptosis, and circumvention of telomere shortening and chromosomal aberrations and translocations. Stage 2 could be initiated by down and up-regulation of angiogenic signaling factors, and stage 3 by dysregulation of various cell-cell-adhesion molecules. Given this hideous degree of complexity, deciding which of these targets would be the most effective to pursue should be a matter of extensive comparative experimentation. This is why it may be preferable to *rely on the unique molecular signature of each tumor.*

SIGNIFICANCE

From its inception, the use of ASO phosphorothioate (PS) analogs have been applied in attempts to downregulate various cancer genes.[4, 5] However, the significance of this proposal is the attempt to use several oligos in a cocktail targeted against genes known to be up-regulated during carcinogenesis or found to be up-regulated during microarray genetic analysis of specific cancers. Let us say for the sake of argument that each of the three oligos is only 60% effective alone. Nevertheless, the 40% of cells unaffected by the first oligo will be 60% cured by the second oligo, that is, 16% are unaffected, and these, in turn, will be 60% cured by the third oligo that is 6.4% unaffected. In other words, using three different oligos against three different mRNA targets can, in principle achieve ca, 94% effectiveness. Of course, the eventual result will depend on how effective each oligo will actually be, and whether or not the effects will be additive, but you can see how this approach can achieve a significant amplification effect. One might also hope that the effect of two or three ASOs could be synergistic.

EXPERIMENTAL CONSIDERATIONS

Literature Analysis: For 40 years, ASO analogs have been employed in downregulating cancer genes in experimental research and as therapeutics ("genetic medicines") in cancer therapy. We conducted a series of literature searches using various search engines using the term "antisense oligonucleotide" combined with various other terms of interest. The results are displayed in **Table 1**.

Table 1. Literature Searches for Antisense Oligonucleotide[1]

Plus	Scifinder-n[2]	WoS[3]	PubMed[4]
Cell line	6,146	443	1,112
Oncogene	1,957	247	755
Angiogenesis	1,016	222	133
Metastasis	1,403	195	129
Tumor suppressor gene	97	135	13
DNA repair gene	6	0	0
Cell line and oncogene	774	48	280
In vivo	2,953	1,332	862

[1] All searches of phrases were included within quotation marks.
[2] Scifinder-n is the chemical search engine of the ACS.
[3] Web of Science is the search engine used for Life Sciences.
[4] PubMed is the biomedical search engine of the NLM.

Notably, we were both surprised and pleased at the large number of hits we obtained. This means two things, first of all, the very large number of such studies provides, in effect, a *proof of concept* for this approach, given that so many different ASOs have been used in so many different cancers, both *in vitro* and *in vivo*. But, secondly, it means that to analyze these results and obtain the necessary information about cancer cell lines studied, genes targeted and ASOs used, will be a challenging task. Of course, there will be significant overlap between the three search engines used: Scifinder-n for the chemical literature, Web of Science for the life sciences literature, and PubMed for the medical literature. We need to find an automatic means of "mining" this data from the thousands of search results. It will be one of our first steps in this project to find a means to do this, perhaps using an AI-based data mining program.

Target Sequences in Cancer Cell Lines: Once we have carried out an analysis of all the literature searches and removed duplicates, we will need to discover how many cell lines and genes have been targeted successfully by which ASO sequences and if some have been used repeatedly.

These should be the ASOs we can use in our studies to attempt to obtain increased efficacy with more than one oligo

Combinations of ASO Analogs: In each cancer cell line used, we will target those genes that are involved in various aspects of carcinogenesis and in angiogenesis and /or metastasis if available. We will use combinations of two or three oligos targeted against different genes, and for each set of three oligos, this would involve seven combinations (1, 2, 3, 1-2, 1-3, 2-3, 1-2-3). Once we have established a pattern of relative effectiveness, we would go on to the use of human tumors in nude mice with the same or similar combinations of ASOs.

Types of ASO: We intend to have the ASO synthesized almost certainly as the phosphorothioate (PS) analogs that seem to have been the most successful type. However, there are competing claims by the users of various analogs,[1], and we hope soon to have the results of comparative molecular dynamics studies[6] of the duplexation of the most commonly used analogs,[3], which hopefully can guide us as to which chemically modified analog is preferable*.

INNOVATION

The approach outlined in our proposal has the potential to become an effective novel therapeutic approach to cancer as well as a method of cancer prevention. The very large number of studies published that show the efficacy of ASOs *in vitro* and *in vivo* against cancer genes provides in effect a *proof of concept* as a basis for these studies. Also, there have been quite a number of such ASOs approved by the FDA for clinical use.[7, 1]

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* Recently Cy A. Stein published an article entitled "Phosphorothioates and Me" (Nucl. Acid Therap. https://doi.org/10.1089/nat.2024.0032), which unusually has no references! In this he states: "I began to work in the oligonucleotide field during the first week of March 1987, when as a medical oncology fellow, I joined a laboratory at the NIH, which had recently commenced studies with phosphorothioate (PS) oligonucleotides (oligos) to silence HIV gene expression." That laboratory was in fact mine, officially The Section of Biophysical Pharmacology of the Clinical Pharmacology Lab. NCI. I provide the key citations here. Our prior work led to the initial publication: Matsukura, M., Shinozuka, K., Zon, G., Mitsuya, H., Reitz, M., Cohen, J. S., and Broder, S. Phosphorothioate Analogs of Oligodeoxynucleotides as Novel Inhibitors of Replication and Cytopathic Effect of Human Immunodeficiency Virus, *Proc. Natl. Acad Sci. USA. 84:* 7706-7710, 1987. His research project led to the subsequent publication: Stein, C. A., Subasinghe, C., Shinozuka, K., and Cohen, J. S. Physicochemical Properties of Phosphorothioate Oligodeoxynucleotides, *Nucl. Acids Res. 16:* 3209-3221, 1988. He subsequently had 20 co-authored publications from my laboratory (3 of them reviews), some with other collaborators.

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Feature Articles

Chemical Terms in History: Polysemy and Meaning Transfers

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Abstract. The vocabulary of the chemical sciences consists in part of words and phrases many of which are of a technical nature while others are derived from or related to everyday language. Many of the words are so-called polysemes, that is, they are used with different meanings either in common language or in the technical language of other sciences. The study of the origin and migration (or transfer) of words in science provides additional insights in how science has developed historically and interacted with the cultural domain. One type of word migration is between the scientific and socio-cultural domains, while another is restricted to the transfer between different scientific disciplines or sub-disciplines. This paper discusses and exemplifies a select number of chemically related words and phrases from a historical perspective. Among them are commonly known words such as 'radical,' 'catalyze,' and 'litmus test' which are used not only as technical terms in chemistry but also, in figurative and metaphorical senses, in everyday language.

Keywords: history of chemistry, language, words, polysemy, semantic shifts, radical, bromide, DNA

1. INTRODUCTION

When chemists speak of the language of their science they typically refer to the nomenclature related to the numerous chemical compounds and how their names and symbols have changed over time. What once was known as 'fixed air' is now called carbon dioxide CO_2; what is commonly known as just alcohol is ethanol C_2H_5OH in chemical language. Lavoisier's chemical revolution in the 1780s traditionally hailed as the beginning of so-called modern chemistry was to a large extent based on a radical reform of chemical nomenclature. The collaborative work *Méthode de Nomenclature Chimique* from 1787 was not only "a momentous contribution to the world-wide vocabulary of Western science," as it has been called,[1] but also an integral and most important part of the chemical revolution.

However, there are other ways in which a focus on words and phrases may elucidate the historical development of chemistry and science generally. One of them is to pay attention to what linguists call 'semantic shifts,' an expression that refers to words which migrate from the scientific domain to common language and as a consequence change their meaning. But it can also be the other way around, that is, a commonly known word which is adopted as a technical term in a particular area of science. A third variant of semantic shifts occurs when a technical term in one branch of science is reused in another branch, what may be called internal word migration. Although the term in question is the same, when reused it occurs with a different meaning. As pointed out by the linguist Carolynn Van Dyke, the reuse or recycling of words is not a one-way transfer since recycled scientific terms will often return to the domains, scientific or non-scientific, from which they originally came.[2]

More generally, this study is part of a larger project focusing on the etymological and terminological components of the natural sciences through history.[3] In science as elsewhere, words are more than just words. Like other communicative cultural forms, science depends crucially on the chosen language and the words of which it consists. Since the history of science is echoed in the development of its language, an examination of the latter will inevitably provide additional insights in how various branches of science have developed over time.

2. POLYSEMIC TERMS IN CHEMISTRY

Words and phrases generally have multiple coexisting meanings, a phenomenon known as *polysemy* ('many signs' in ancient Greek, πολύ σήμα). Ordinary language is polysemic insofar that most of its words admit of more than one meaning. The few which do not are called monosemic. Polysemic terms abound in science if not quite as frequently as elsewhere. An everyday word often turns up in a scientific context with a specialized and very different meaning, which may cause confusion to chemistry and other science students. Polysemy turns out to be an obstacle in science learning and has for this reason attracted critical attention in educational and didactic contexts.[4] As an American chemistry teacher half-jokingly commented:

> Thus, 'gas' is not what you put in your car, nor is an 'Ideal Gas' one which gives good mileage; 'precipitation' refers to the formation of solids and not to rain; 'acids' are not psychedelic drugs and 'basic' does not mean fundamental; not all pleasant-smelling chemicals are 'aromatic'.[5]

There are several other words in this category of multiple meanings which are used in both scientific contexts and everyday language. If used in a technical sense, their meanings often differ from one area of science to another. Familiar terms such charge, matter, resonance, force, power, and specific (as in 'specific heat') are random examples.

Other polysemic terms of chemical and biochemical relevance are 'culture,' 'mole,' 'solution,' and 'spontaneous' (more examples are discussed below). Apart from its general meaning, since the 1880s *culture* also refers to the production of bacteria or other microorganisms in the biological laboratory. A *mole* is a small animal primarily living of earthworms but also a chemical unit given by Avogadro's number of molecules or other particles.[6] The *molar* concentration is the number of moles per unit volume, an adjective, whereas the noun molar refers to a tooth. When we think to have found the answer to a problem, we have found its *solution*. In mathematical usage the solution to the cubic equation $x^3=8$ is $x=2$, but in chemistry the term typically refers to a substance dissolved in water or some other liquid. Again, the common meaning of *spontaneous* is an immediate and unconstrained action or thought. On the other hand, thermodynamically favored chemical reactions (e.g. $2H_2+O_2 \rightarrow 2H_2O$ at room temperature and in the absence of a catalyst) are said to occur spontaneously even though they occur with a reaction rate close to zero.[7]

The word *earth* is polysemic given that it appears in different contexts with each their separate meanings. As used by astronomers and geologists the term chiefly refers to our planet and as such it is often written with capital first letter, Earth. In an agricultural context the term is a synonym for 'soil' and to Empedocles and the ancient Greeks it was an elemental principle on par with 'air,' 'water,' and 'fire.' Chemists and mineralogists in the eighteenth century typically used the term 'earth' in both its singular and plural form (earths), namely as a designation of substances later identified as metallic oxides or carbonates. As a reminiscence of the past we still speak of the 'rare earths' but now as a group of metallic chemical elements largely identical to the lanthanide series in the periodic table.

3. INTERNAL WORD MIGRATION

As mentioned, in many cases words and phrases do not migrate between the social and scientific spheres but within the latter, that is, between different fields or subfields of science. It is not uncommon that a technical term originating in one scientific discipline is subsequently adopted with a different meaning in another discipline. One example among many is the term *pyrene* (or pyrena) which in botany denotes a fruitstone within a drupe, whereas in chemistry the same word refers to an organic compound consisting of four benzene rings with the stoichiometric formula $C_{16}H_{10}$ (Fig. 1). The botanical pyrene is derived from Greek 'pyren' or 'pyreno' (πυρήν) meaning fruitstone, whereas the chemical pyrene refers to 'pyr' or 'pyro' (πύρ) meaning fire. Of a somewhat different kind is the history of the term *plasma,* which entered scientific language as blood plasma and much later migrated from medicine to physics as the name for the very different phenomenon of a fourth state of matter.[8]

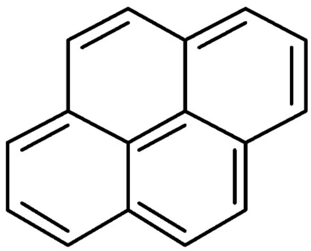

Figure 1. The structural formula of pyrene.

A word migration of an approximately similar kind can be followed in the term *chain reaction* which today is mostly associated with the fission process in which nuclear energy and new neutrons are generated explosively in a lump of enriched uranium. However, 'chain reaction' was originally coined in 1921 to describe the reaction kinetics of photochemical and other processes (e.g. $H_2+Cl_2 \rightarrow 2HCl$). It was a widely used term in chemistry and biochemistry years before it was adopted with a new meaning by the nuclear physicists at the end of the 1930s. Later again the term was used in a variety of figurative and metaphorical senses.[9]

Darwinian evolution theory provides an interesting case of how characteristic words and phrases belonging to the biological realm migrated temporarily to chemistry in the last quarter of the nineteenth century. Among those who explicitly invoked Darwin's biological theory in more than just a rhetorical sense was the Austrian physical chemist Leopold Pfaundler, the Danish thermochemist Julius Thomsen, and the British chemist William Crookes.[10] For example, in an address to the 1886 meeting of the British Association for the Advancement of Science Crookes advocated what he called 'inorganic Darwinism' including the suggestion that the known elements were "the gradual outcome of a process of development, possibly even a 'struggle for existence'."[11] Moreover, stating that "The array of the elements cannot fail to remind us of the general aspect of the organic world" he mentioned as an example "the Monotremata [platypus, echidnas] of Australia and New Guinea, and among the elements the metals of the so-called rare earths."

In some cases, science words just happen to be duplicated with a new meaning and in a new field without any connection to or knowledge of the earlier use of the term. If so, the term does not 'migrate' from one field to another – as plasma did – but is independently introduced in two fields with different meanings. As one example, consider the short-lived neologism *metabolon* that Ernest Rutherford and Frederick Soddy coined in 1903 for unstable decay products of radioactive elements. The very same term was independently reinvented 82 years later by the Hungarian-born American biochemist Paul Srerer when looking for a term describing various molecular complexes of metabolic enzymes:

> Communication about such complexes might be facilitated if a single word were available for them. … It seemed clear that no simple word could convey in its own structure the concepts I have discussed so … I propose, therefore, the word 'metabolon' for a 'supramolecular complex of sequential metabolic enzymes and cellular structural elements'.[12]

In what follows I present nine brief case studies (4.1-4.9) of words which in one way or other illustrate how the meaning of scientific terms have changed over time and often crossed the barrier between scientific and everyday language. Most of the examples, which are here limited to the English language and given in no particular order, refer to fields of chemistry and their history.

4.1. ENERGY

Although not specifically a chemical term, since the 1860s *energy* has been a fundamental concept in chemistry. It is often stated that in the scientific sense, 'energy' was coined by the English polymath Thomas Young in a lecture of 1802 although at the time he referred only to the kinetic energy (or, to be precise, to the *vis viva* given by mv^2 and not $\frac{1}{2}mv^2$).[13] Several decades later, with the discovery of energy conservation, 'energy' was adopted as a key term in the physical sciences except that initially it was mostly called *force* in English, *Kraft* in German, and *puissance* in French. It took until the 1870s before 'energy' became the favored term among physicists, chemists, and other scientists.

However, 'energy' had entered the English language long before if as a religious and metaphysical term or sometimes as an expression for the active powers of either nature or humans. The painter, poet and mystic William Blake composed in the early 1790s a book in which 'energy' appeared in a sense completely different from the one we now associate with the term. "Energy is Eternal Delight," Blake declared," adding that "Energy is the only life and is from the Body and Reason is the bound or outward circumference of Energy."[14] A generation earlier, the 1720 edition of Edward Phillips' dictionary *New World of Words* explained:

> Energy, effectual Working, Efficacy, Force: In *Rhetorick*, a Figure wherein great Force of Expression is us'd: In a Medicinal Sense, a stirring about, or Operation of the Animal Spirits and Blood.[15]

As late as 1842 – the year of J. Robert Mayer's first formulation of the principle of energy conservation – the *Encyclopaedia Britannica* defined energy as "a term of Greek origin, signifying the power, virtue, or efficacy of a thing. It is also used figuratively, to denote emphasis of speech."[16] But then things changed. Thirty-seven years later, the same authoritative dictionary included a detailed 7-page article on energy in its modern sense.[17]

According to a recent study, the term energy originated in a cultural context from which it migrated to the fields of science and then, eventually, migrated back to culture with a new meaning.[18] Although 'energy' today mostly refers to the physical entity dating from the mid-nineteenth century – an entity which has for long become a commodity and the consumption of which we pay for – the old meanings have persisted and new have been added. We may still speak of energy as a personal quality, say 'a man of great energy' and we understand, more or less, what is meant by 'mental energies' or a metaphorical phrase like 'the city was buzzing with energy.' Although energy has no color, we speak metaphorically and sensibly of the renewable 'green energy' versus the 'black energy' based on coal and natural gas. The polysemic term energy is all over in our language, scientific as well as non-scientific. While in 1800 it occurred with a frequency of 40 times per million words in written English, and in 1900 with 80 times, today the frequency is about 200 per million words, which makes it one of the 500 most common words (OED, *Oxford English Dictionary*).

4.2. LITMUS TEST

One of the simplest and most common experiments in elementary chemistry is the *litmus test* in which the acidic or basic character of a solution is demonstrated by means of a litmus paper. If the paper turns blue, the solution is basic (pH > 8.3) and if it turns red the solution is an acid (pH < 4.5). The English name 'litmus' for a substance extracted from various lichens is derived from old Norse *litmos* meaning 'moss used for dyeing' and was in the seventeenth century typically spelled 'lytmos' or 'lyttmosse' (OED). It may have been known as an indicator by Robert Boyle, but it was only with the French chemist Antoine Fourcroy in the 1780s that the litmus test was used systematically for analytical purposes.[19] In 1803 Humphrey Davy referred in one of his investigations to the manufacture of crystals of gallic acid, and "a fluid came over, which reddened litmus-paper."[20] Eventually, the qualitative test became a standard remedy in nineteenth-century school chemistry.

As a figurative term or metaphor emancipated from its chemical meaning 'litmus test' only entered the English language in the second half of the twentieth century, typically in the sense of a crucial indication that something is actually the case or has succeeded. 'The passing of the bill was a litmus test for the new government,' a newspaper may report. Or we may be told that with the solar eclipse observations of 1919 Einstein's theory of general relativity passed a litmus test, which in this sense corresponds to a so-called crucial experiment. Such phrases with somewhat different connotations are very common in today's plain language. *Britannica Dictionary* defines a litmus test normatively, namely as "something (such as an opinion about a political or moral issue) that is used to make a judgement about whether someone or something is acceptable."[21] Indeed, in this sense the term litmus test has been employed in American political language since the mid-twentieth century. To give just one more example of non-chemical use of the term, in 1985 the famous German philosopher and sociologist Jürgen Habermas published an article with the title "Civil Disobedience: Litmus Test for the Democratic Constitutional State."[22] That is, by making a direct analogy to the chemist's test of acidity, Habermas argued that civil disobedience was a crucial test of whether a nation was truly democratic or not.

4.3. 'GOOD CHEMISTRY'

When two persons are said to have a 'good chemistry,' it typically means that they easily come along, enjoy being together, or have an intuitive feeling of what the other is thinking. If Johnny tells Linda that 'Well, there just wasn't any chemistry between us,' Linda knows what he means. An American newspaper reported about a basketball team: "Injuries have hurt our chemistry, and team chemistry is such a delicate thing."[23] It is not obvious what chemistry has to do in phrases like these, but there is help to find in George Bernard Shaw's play *You Never Can Tell* from 1897. Gloria says to Valentine, "I hope you are not going to be so foolish – so vulgar – as to say love," to which Valentine replies:

> No, no, no. Not love: we know better than that. Let's call it chemistry. You can't deny that there is such a thing as

> chemical action, chemical affinity, chemical combination – the most irresistible of all natural forces. Well, you're attracting me irresistibly – chemically.[24]

The old polysemic word *affinity* is the key term. Around 1700 it was associated with human relationships and not with the reactivity of chemical substances, such as illustrated by the definition in *World of Words*: "Affinity, Kindred or Alliance by Marriage; Relation or Agreeableness between several Things."[25]

Apart from its many other connotations the concept of affinity has played a crucial role in the history of chemistry, where it originally was an expression for the 'sympathy' between two chemical substances of the same 'affection.' Only by the mid-eighteenth century did chemists begin to speak of the affinity of a substance for other substances *unlike* it rather than *like* it. The poorly defined concept could be conceived as a kind of force causing some substances to combine and others not. Later attempts to turn the elusive affinity into a measurable quantity resulted in elaborate electrical and thermal theories of 'elective affinity' until it was largely replaced by the free energy of current chemical thermodynamics.[26]

There is another common expression with scientific and semantic roots similar to the one of 'good chemistry.' If two or more people understand each other well or can easily cooperate – are 'of the same mind' – they are said to be 'on the same wavelength.' The idiom, which has been in use since the 1920s, alludes to the reception of radio programs at a particular wavelength sent through 'the ether.'[27] It would make no sense before the invention of radio. Although 'good chemistry' is usually a phrase referring to the mutual feelings between people, recently it has also been employed to express in a figurative manner a person's 'body chemistry' (or personality) as in the perfume brand simply called Good Chemistry.[28]

4.4. VITRIOLIC

In the eighteenth century, strong sulfuric acid was known as 'oil of vitriol' or 'vitriolic acid' because it was manufactured from sulfates or 'vitriols,' a name that comes from the Latin word *vitrum* for glass. The sulfate crystals looked like pieces of colored glass. Iron sulfate $FeSO_4$ was called 'green vitriol' and earlier 'vitriol of Mars,' and copper sulfate $CuSO_4$ was 'blue vitriol' or 'vitriol of Venus.' Stannous sulfate alias tin(II) sulfate $SnSO_4$ was known as 'vitriol of Jove,' a reference to the planet Jupiter or the Roman god of the same name. In the more systematic nomenclature of the late eighteenth century, Latin-based names such as *magnesia vitriolata* ($MgSO_4$) and *vitriolicum potassinatum* (K_2SO_4) were commonly used.[29] The term *vitrum* was also known from the new science of electricity, where the electric fluid generated by the friction of glass was known as *vitreous* and the one related to wax as *resinous*. These now obsolete words soon became known as, respectively, positive and negative electrical charges, a terminology introduced by Benjamin Franklin in about 1750.

Another common substance was the 'caustic soda' or what later became sodium hydroxide (NaOH). While sulfuric acid is a strong acid and sodium hydroxide a strong base, the two substances have in common that they are highly corrosive and therefore dangerous. The words are used figuratively in approximately the same sense, namely to denote speech or behavior which is bitterly critical, harshly condemnatory, or sarcastic in an unkind way. The OED defines the figurative senses of the two adjectives as follows: "vitriolic: Extremely sharp, caustic, or scathing; bitterly ill-natured or malignant," and "caustic: That makes the mind to smart; said of language, wit, humor, and, by extension, of persons; sharp, bitter, cutting, biting, sarcastic."

A person may launch 'a vitriolic attack' against some other person by making use of a 'caustic rhetoric.' More recently the metaphoric phrase 'oxygen of publicity' has crept into the language as an expression for how the mass media may indirectly boost questionable or harmful causes. In a speech of 1985, Britain's prime minister Margaret Thatcher said that "we must try to find ways to starve the terrorist and the hijacker of the oxygen of publicity on which they depend."[30]

4.5. BROMIDE

To chemists, a bromide is a salt containing the negative bromide ion Br^- just as a chloride contains the ion Cl^-. Sodium bromide is NaBr, potassium bromide KBr. But in literary usage the same word signifies a cliché, a banality, or a feel-good phrase, for example 'Time heals all wounds,' 'Boys are boys,' and 'You don't look a day over fifty.' Any connection between the two very different meanings? Yes, there is one.

In the mid-nineteenth century is was discovered that potassium bromide in particular had calming effects and could be used as a sedative, a remedy for headache, and even, so it was claimed, to treat epilepsy and forms of hysteria. In 1869, an American professor of medicine reported in *Scientific American*:

> Of all the sleep-producing agents at our disposal, the bromide of potassium is most deserving the name of hypnotic. A healthy adult may take from twenty to thirty grains three times a day; the latter dose is not too large. … Bro-

mide of potassium occasionally produces also a great lowness of spirits, and a disposition to cry. It should be administered very much diluted.[31]

Although the detrimental effects of the substance had become clear by the 1880s, its popularity and overuse continued for several decades. The active ingredients in Nervine, a sedative used for a number of nervous disturbances, was potassium bromide mixed with sodium and ammonium bromides. Bromo-Seltzer or just 'bromo' based on sodium bromide and acetanilide was very popular as a pain reliever for headaches and hangovers in particular (Fig. 2).[32] Only in 1975 did the U.S. health authorities outlaw bromides in over-the-counter medicines. With the popularity of bromine-based medicine followed that 'bromide' came to be used figuratively for anything or anyone that might put one to sleep because of commonness or plain dullness.[33]

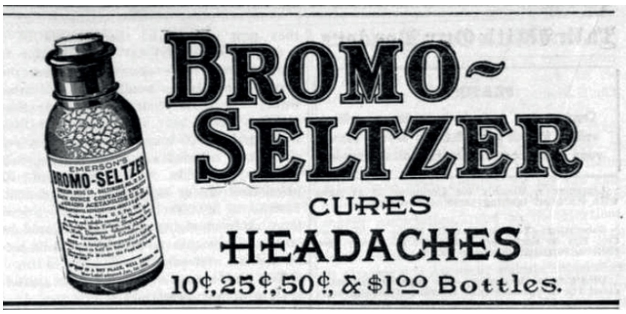

Figure 2. An advertisement for Bromo-Seltzer manufactured by Emerson Drug Co., Baltimore. Google Pictures.

As early as 1906, an American author, Gelett Burgess, published a humorous booklet with the full title *Are You a Bromide? Or, the Sulphite Theory Expounded and Exemplified According to the More Recent Researches into the Psychology of Boredom Including Many Well-Known Bromidioms Now in Use*. While boring and utterly predictable people were *bromides*, the much rarer group of people thinking by them themselves and speaking accordingly were *sulphites*. Coining the word *bromidioms*, a shortening of bromide-idioms, Burgess listed a large number of such expressions. One of them was "This world is such a small place, after all, isn't it?" and others were "That dog understands every word I say" and "Now, this thing really happened!"[34]

4.6. HYBRIDIZATION

The terms *hybrid* and *hybridization* appear in half a dozen sciences, most notably in biology (genetics), linguistics, and chemistry, but also in computing, geology, and particle physics. More recently 'hybrid' has become popular as a name for a car or other vehicle powered by a combustion engine and one or more electric motors. In the case of linguistics, a hybrid word (also called a *hybridism*) is one that etymologically derives from two or more languages. Many English words combine Latin and Greek parts and are thus hybrids, random examples being *television* and *chloroform* (Greek-Latin), and *calorimeter* and *terminology* (Latin-Greek). The language of quantum mechanics includes German-English hybrid words such as *eigenvalue* and *eigenstate*.

'Hybrid' and 'hybridization' (the formation of a hybrid) are usually associated with the offspring resulting from cross breeding, say a mule from a horse and a donkey, and in this sense they are well known and have been used for long. It is less well known, at least in the general public, that they also have a significant place in the chemists' vocabulary as terms describing the bonds that keep atoms together in a molecule. To explain the structure of methane CH_4, chemists in the early 1930s reasoned that the 2*s* and 2*p* orbitals of the carbon atom hybridize to form overlapping sp^3 orbitals.[35]

It is widely agreed that this concept from the early MO (molecular orbital) theory of quantum chemistry was introduced by the eminent chemist Linus Pauling, who in a letter to Charles Coulson claimed that he had "discovered (or invented)" the concept of hybridization as early as 1928.[36] However, at the time he did not employ the terms 'hybridization' and 'hybrid' which first appeared in print in a 1931 paper written by another Nobel Prize-winning chemist, namely Robert Mulliken:

> All the outer orbits are so much modified that we no longer should distinguish 2*s* and 2*p* orbits, but may better think, in CH4, in terms of four new 2-quantum orbit-types, each of a sort of hybrid of 2*s* and 2*p*, with 2*p* predominating in the mixture. … If the molecule is sufficiently stable, a hybridization of *s* and *p* electrons may occur.[37]

Pauling was most likely inspired by the biologists' familiar use of the terms. In 1931 he was invited to give a seminar to a group of biologists, and, according to historian of science Mary Jo Nye: "Wide-ranging readings in biology soon spilled over in his thinking about the chemical bond. The 'changed quantization' of 1928 and 1931 became widely known as 'hybridization' by the late 1930s."[38] Without going into further details it is obvious that in this case the terms were borrowed from much earlier usage, namely from farmers' breeding of animals. The chemists simply adopted a familiar terminology which they extended to a new area of atomic and molecular chemistry. The extension was scarcely noticed by people outside the chemical community and definitely not by the general public.

4.7. CATALYSIS

Contrary to 'hybrid,' the word *catalysis* and associated terms like 'catalyze' and 'catalyst' are largely chemical in origin and were subsequently transferred to other areas including everyday language. They go back to Jöns Jakob Berzelius, the famous Swedish chemist who was also a prolific chemical wordsmith responsible for neologisms such as 'isomer,' 'halogen,' 'protein,' and 'polymer.'[39] In his *Jahres-Bericht* of 1835 he pointed out, as others had done before him, that small amounts of a substance might drastically increase the reaction rate without being consumed in the reaction.[40] Ascribing this class of remarkable phenomena to a "new force in inorganic and organic nature, bringing into being chemical activity," he said:

> So long that its nature and relations are unknown it will be convenient to consider it a new force, and to give it a name. I will, using a derivation well known in chemistry, call it the *catalytic force* (katalytiska kraft; katalytische Kraft) of the bodies, and the decomposition it produces *catalysis*, just as the separation by ordinary chemical affinity is called analysis.[41]

Notice that Berzelius did not claim his terms to be proper neologisms as they were derivations "well known in chemistry." The word catalysis is derived from Greek *katalysis* (κατάλυσις) meaning 'dissolution' or 'to dissolve' and with approximately this meaning, or sometimes with the connotation 'destruction,' it can be found in the seventeenth century in both chemical and non-chemical contexts. In his influential Latin work *Alchemia* from 1597, Andreas Libavius used 'catalysis' but in the sense of the decomposition of base metals into silver and gold.[42] Whereas Berzelius defined or redefined 'catalysis' and 'catalytic,' the noun 'catalyst' for a catalytic agent came into use only in the early years of the twentieth century. According to OED it first appeared in print in 1902.

As it turned out only many years later, the mere presence of a catalyst is not enough for its action. It does take part in the reaction it catalyzes, but is reformed before the reaction is over. Berzelius' terms soon became very important in chemistry and biochemistry, and from about 1940 they also turned up with extended meanings. An American newspaper referred in 1943 to the new science of supersonics which "may usher in a new age of chemistry with radio being used as a catalytic agent."[43] The words also gained a footing in common language, typically as something or someone causing an event to happen. Thus, an individual or an organization may be said to catalyze a movement by spearheading innovative ideas and inspiring others to take action. The figurative meaning is close to but not quite the same as the chemical notion of catalysis, where a catalyst speeds up the reaction but does not cause or activate it.

4.8. RADICAL

The term *radical* exists both as a noun and, what is more common, as an adjective. It has its origin in the Latin word *radix* for 'root,' which is reflected in one of the meanings of 'radical,' namely the root or base of something. We have the word in the edible vegetable 'radish' and also in the verb 'eradicate' meaning to root something out. This is also the connection to the algebraic 'square *root*,' where the symbol in $\sqrt{x}$ is called a radical and the number x a radicand. More generally, the expression $x^{1/n}=\sqrt[n]{x}$ is the nth root of x.

In present usage the term 'radical' is often associated with politics and the social arena. Extreme political views and corresponding ideologies are said to be radical and the same term is applied as a noun for persons adhering to such views. In this political and religious sense 'radical' has been known since about 1800 but only became common in the 1960s. Sympathizers of the radical views of Islamic State (IS) are often said to have been *radicalized*. Einstein's theory of relativity was considered too radical by many contemporary physicists, meaning that it was a revolutionary break with the past.

The term also appears prominently in the history of chemistry, but with a variety of meanings which seem to have no connection to the mentioned examples. Thus, in chemistry there is no concept of *radicalization* – the process of making or becoming increasingly more radical – such as there is in the socio-political sphere. Nor is the noun *radicalism* as in 'left-wing radicalism' a chemical term. When modern chemists speak of a radical, they are referring to an atom, molecule, or ion with one or more unpaired valence electrons such as the chlorine atom Cl·, the hydroxyl radical HO·, and the methylene molecule $:CH_2$. Such particles are highly reactive and under normal conditions they can exist only for a very short time.

The concept of radicals entered chemical language in 1782 with a work by the French chemist Guyton de Morveau, who based the name on the Latin *radix*.[44] Morveau's notion was completely different from ours, as he essentially used it to denote the principle or 'acidifiable base' of an acid or, in the language of Lavoisier, the part of the acid containing oxygen. In his famous textbook *Traité Élémentaire de Chimie* from 1789 Lavoisier also wrote of, for example, the 'muriatic radical' for what later became chlorine.[45] While Lavoisier's use of 'radical' for an element did not win approval, the term persisted for a combination of elements involving carbon and hydrogen in organic compounds. For example, in this sense the idea of radicals became an integral part of Berzelius' electrochemical system. "In the case of plant substances, the radical generally consists of carbon and hydrogen, and in the case of animal substances of carbon, hydrogen and nitrogen," he wrote.[46] In the period from about 1810 to 1850 chemists generally thought of radicals as those stable and pre-existing parts of a chemical substance, whether simple or complex, that persisted with unchanged identity through chemical reactions.

Without going into the complicated history of the nineteenth-century radical theory,[47] the concept named 'radical' by contemporaneous chemists was entirely different from what modern chemists associate with the term. In recent years there has been much public attention to so-called *free radicals* and their effects on health. Free radicals generated in the body may be harmful in a number of ways. However, their physiological actions can be countered by antioxidants donating an electron to the radical and thus neutralizing it. To the extent that the general public knows about the chemical term 'radical' it is most likely in connection with the health aspects of free radicals and antioxidants. Although 'free radicals' have migrated from the chemists' laboratories to commercial health and beauty clinics, the meaning of the term has not changed to any extent.

4.9. DNA

An *acronym* is a word which is usually, but not always, formed by the initial letters of a longer word or phrase as in IUPAC (*I*nternational *U*nion of *P*ure and *A*pplied *C*hemistry) and DDT (*d*ichloro*d*iphenyl*t*richloroethane). The term itself is a neologism of recent origin as it only appeared in print in early 1943. Although abbreviations of this kind were known earlier, they only entered the language of science significantly after World War II and have since then increased explosively in number and variation.[48] One of the earliest and most widely used scientific acronyms is DNA, an abbreviation of *d*eoxyribo*n*ucleic *a*cid which according to OED dates from 1944. However, not only can DNA be found in the literature two years earlier in a paper by the American biochemist Seymour Cohen, so can the related acronym RNA (*r*ibo*n*ucleic *a*cid).[49]

It took more than a decade before the abbreviated form DNA was adopted by biochemists and molecular biologists, but with James Watson's and Francis Crick's sensational discovery of the double-helix DNA structure the acronym became increasingly popular. Incidentally, in their landmark paper in *Nature* from 1953 Watson and Crick still referred to 'deoxyribose nucleic acid' and only used D.N.A. (not DNA) once.[50] At the time of the Watson-Crick discovery the acronymic term DNA was a decade old and the substance had been known since 1871. In experiments completed two years before his paper appeared, the 25-year-old chemically trained Swiss physiologist Friedrich Miescher succeeded in isolating an impure form of DNA from the nuclei of white blood cells. What Miescher called *nuclein* was essentially the same as our DNA.[51]

The abbreviated form of deoxyribonucleic acid has been remarkably successful not only in the biochemical and medical sciences but also beyond. According to an analysis based on more than 24 million scientific article titles and 18 million article abstracts published between 1950 and 2019, the DNA acronym appeared about 2.44 million times.[52] Nearly half a million scientific papers include DNA in its title (Web of Science). As another measure of its success, in the period from about 1980 to 2020 the term DNA has appeared in the general book literature with a frequency of approximately 45 per million words, which makes it as frequently used as common words such as efficient, egg, and shop (Fig. 3).[53]

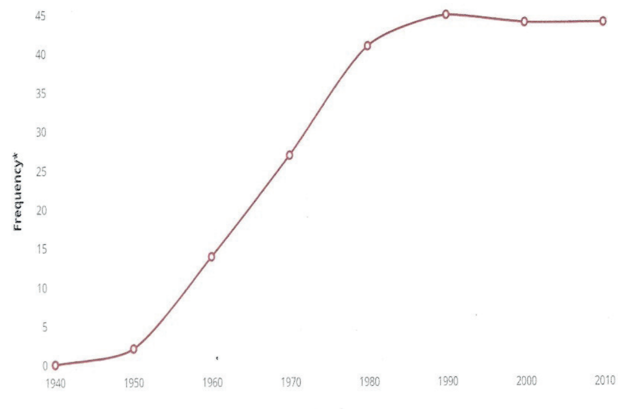

Figure 3. The word frequency of the abbreviation DNA in ppm between 1940 and 2010. Source: OED.

Moreover, metaphoric and figurative senses of the term DNA have for long been part of everyday language with the acronym effectively functioning as an independent word, a so-called pseudo-neologism. It is used by ordinary speakers or writers without knowing of or caring about its origin in the more cumbersome word 'deoxyribonucleic acid.' There is little doubt that had it not been for the abbreviated form this would not have happened. Nor would word formations such as 'DNA fingerprint' and 'DNA profiling' have been possible. In an interview of 2015 Barack Obama said, "the legacy of slavery … casts a long shadow. And that's still part of our DNA that's passed on."[54]

Today DNA is often used figuratively as signifying the essence of a person or a thing, as in 'it is part of her DNA' or in an advertisement saying 'we build good cars because it's in our DNA.' It is hard to imagine an advertisement with the alternative 'we build good cars because it's in our deoxyribonucleic acid.' As the term 'good chemistry' is used commercially in the perfume industry, so is it the case with DNA suggesting that a particular perfume expresses the user's personality. "People are individuals … [and] I match an individual's DNA print into the fragrance," says a perfume designer.[55]

5. CONCLUSION

In this paper I have called attention to certain linguistic concepts such as polysemy, semantic shifts, and word migration as resources in the history of science and the history of chemistry in particular. These and related concepts are illustrated in a concrete manner by examples of chemical terms and their histories ranging from the sixteenth to the twentieth century. To summarize, in transfer or migration processes a term *X* appears in one domain and is later adopted – in the sense borrowed – in another domain with a different meaning. One of the domains in question can be the common language, but the transfer process can also occur between two fields of science, say astronomy and chemistry or geology and physics. Moreover, it sometimes happens that *X* is independently reinvented in one domain without any connection whatsoever to the previous use of *X* in another domain. When a polysemis term is recycled it does not generally imply that the older meaning is abandoned. On the contrary, it frequently happens that two or more meanings of *X* peacefully coexist for a longer period of time.

To understand scientific texts of the past and avoid anachronisms one must be aware that many of the key terms have changed semantically and often drastically so. Because a certain key term was coined in the 1830s and subsequently became very popular it does not mean that the concept described by the term remained the same. Thus, Michael Faraday's 'ion' from 1834 differed significantly from the entity of the same name introduced by Svante Arrhenius about fifty years later. Whereas the latter conceived the ion to be an electrically charged particle always present in a solution of an electrolyte, Faraday's concept of an ion was very different.[56]

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Feature Articles

Between al-Rāzī and the Pseudo-Rāzī: Classifying Matter and Composing an Alchemical Handbook

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Abstract. This contribution focuses on two Arabic alchemical treatises that circulated under the name of the 10th century philosopher, physician, and alchemist Muḥammad ibn Zakarīya al-Rāzī: the genuine *Book of Secrets* (*Kitāb al-Asrār*) and the spurious *Book on Alums and Salts*. The two treatises are discussed in the context of al-Rāzī's genuine and spurious production and of their reception among Western scholars. By examining the contents and structural features of these two treatises, this work seeks to shed light on the relationship between perceived authority, structure, and laboratory practice in medieval alchemy.

Keywords: Alchemy; Medieval Science; Early Chemistry; Transmission of Knowledge; Muḥammad ibn Zakarīya al-Rāzī

INTRODUCTION

When, in 1144 CE, the Latin translation of an alchemical epistle attributed to the Umayyad Prince Khālid ibn Yazīd (fl. early 8th c.) started circulating under the title *Liber de compositione alchimiae*, the Latin world had its first exposure to alchemical doctrines that were considered a complete novelty.[1] The innovative character of the materials expounded in this translation is made explicit in a brief text known as *Prefatio Castrensis,* a work that is often connected to the text of the *De compositione alchemiae* and whose authorship is still debated.[2] What appears to be beyond doubt is the fascination that this new translation exerted on its Latin readers. The interest that it sparked is mirrored by the proliferation of Arabic-Latin translations of alchemical works in the 12th and 13th centuries. As highlighted by Moureau, the phenomenon of reception, acquisition, and assimilation of the Graeco-Arabic alchemical heritage into Latin can be roughly described as a sequence of waves, that included: a) translation of Arabic treatises into Latin; b) composition of Latin compendia and works under the strong influence of Arabic models; c) composition of original and autonomous Latin alchemical treatises.[3] It is through this process that the 'canon' of medieval Latin alchemy was formed, a canon that kept influencing alchemists and early chemists up to at least the 18th century.[4] The alchemical material that entered the Latin world reflected the different ways in which alchemists had written about their subject matters in Arabic and in Greek even before: while some authors had kept loyal to the esoteric nature of alchemy and had made sure their alchemical teachings were sheltered from the greedy approach of the uninitiated by employing an allegorical style and a coded lexicon (*Decknamen* and alchemical symbols),[5] others–few and far between–had laid down their teachings on alchemy in plain language and simple prose.

This contribution will focus on two Arabic alchemical works of the latter kind that circulated (genuinely or pseudo-epigraphically) under the authoritative name of the 10th century philosopher, physician, and alchemist Muḥammad ibn Zakarīya al-Rāzī: the *Book of Secrets* (*Kitāb al-Asrār*) and the *Book on Alums and Salts*.[6] After setting the two works in the context of al-Rāzī's genuine and spurious production, and of their reception among Western scholars, I analyse in this article their similarities and differences in contents and structure, and provide materials for problematising the relationship between perceived authority, structure, and practice in alchemy.

THE *BOOK OF SECRETS* AND THE *ON ALUMS AND SALTS*: TWO PRACTICE-ORIENTED ALCHEMICAL HANDBOOKS

The tenth-century polymath Muḥammad ibn Zakarīya al-Rāzī is considered one of the towering figures of medieval Islamic thought. Born in Rayy (now in Iran), his vast production covered medicine, pharmacology, toxicology, alchemy, philosophy, and religion.[7] Al-Rāzī's extant philosophical production represents only a small part of his writings, since the tradition of the works that gained him the fame of 'free-thinker of Medieval Islam' was weakened by a form of *damnatio memoriae:* his most controversial ideas, that included a harsh criticism of prophecy, are now only preserved in treatises by al-Rāzī's opponents who report his opinions in order to criticize them.[8] The lasting fame of al-Rāzī was assured by his career as a physician and director of the hospital of Baghdad and by his medical works, that circulated widely in the Arabo-Islamic world, and became extremely popular in Europe in their Latin translations. Apart from a number of shorter monographs on specific medical topics (and these include, for instance, an innovative treatise *On Smallpox*), al-Rāzī dedicated a major compendium of medicine, the *Kitāb al-Manṣūrī fī al-Ṭibb* ("The Book on Medicine for Al-Manṣūr"), to his patron Manṣūr b. Isḥāq, the Sāmānid governor of Rayy. His students collected also the medical notes and observations of their teacher in the extensive *Kitāb al-Ḥāwī fī al-Ṭibb* ("The Comprehensive Book on Medicine"), which is considered a *unicum* for its time of production, since it contains and reports on several medical cases derived from the physician's daily medical practice and presents an unstructured, yet thorough, approach to medicine.[9]

In the field of alchemy, the works composed by al-Rāzī are listed by the 10th century bibliographer Ibn al-Nadīm in the tenth and final chapter of his *Kitāb al-Fihrist* ("Book of the Index"):[10] a volume composed in twelve sections known as the *Twelve Books*, the first part of which had an autonomous circulation under the title *Al-Madkhal al-Taʿlīmī* ("The instructive introduction"),[11] a *Sirr al-Asrār* ("Secret of Secrets"),[12] a small group of titles that do not appear to have reached us, and the *Book of Secrets,* which will be the focus of this article.

In the introduction of the *Book of Secrets,* al-Rāzī explains his motivation for writing the treatise:

> What led me to write this book was the request of a young student of mine from Balkh called Muḥammad ibn Yūnus, knowledgeable in mathematics (*al-riyāḍiyyāt*), natural philosophy (*al-ʿulūm al-ṭabīʿiyya*) and rhetoric (*al-manṭiqiyya*) […] He asked me […] to put together for him something on the secrets of the works of the Art (*asrār afʿāl al-ṣanʿa*) that could be a guide (*imām*) and an example (*dustūr*) to which he could return.

He then praised the accomplishment of this work:

> I composed this book of mine, and with it I have presented him with what I have never presented to any king nor prince. I have explained to him what is needed for the science of the art (*ʿilm al-ṣanʿa*, i.e. alchemy) [deriving it] from all my books on this topic; I presented him with a concise book […] From the procedure (*tadbīr*) that I have explained, the bodies (i.e. metals, *ajsād*) are elevated gradually to the top of the furnace, his aim is reached with an easy procedure (*tadbīr*), [the bodies] are deconstructed and [then] returned to their first condition (*ḥālatahu al-ūlā*) […]

And underlines the exceptionality of such a plain and explicit exposition of the alchemical art:

> […] If I did not know about the elapsing of my days (*inṣirāf ayyāmī*), […] I would have never collected all that I have collected in one single book through thorough examination.

Finally, al-Rāzī provides a brief outline of the structure of the treatise:

> […] This book of mine includes the knowledge (*maʿrifa*) of three topics: the knowledge of the ingredients (*maʿrifat al-ʿaqāqīr*), the knowledge of the instruments (*maʿrifat al-ālāt*), and the knowledge of the operations (*maʿrifat al-tadābīr*).[13]

Al-Rāzī's claim to have presented his student with a unique compendium of all one needs to know for practicing alchemy is reflected by the exquisitely operational nature of this treatise and its comprehensive table of contents: the *Book of Secrets* appears to truly encompass all one needs to master in order to perform alchemical operations in the laboratory. The fame of its author as an accomplished physician and alchemist together–as will be argued below–with the usability of the contents of the treatise itself cooperated to assure a certain diffusion of the work in Arabic, as shown by the existence of several Arabic manuscript copies of the work in European and Indian libraries.[14] An edition of the Arabic *Book of Secrets* was published in 1964 in Tehran under the sponsorship of the UNESCO; this edition has the merit of allowing access to al-Rāzī's work, but cannot be considered a reliable critical restitution of the text. [15] The production of a critical edition of the *Book of Secrets* remains a scholarly desideratum. The *Book of Secrets* attracted the attention of the 12th century Arabic-into-Latin translators in Toledo and in particular of Gerard of Cremona, whose translation of the first two sections of the treatise is preserved in MS Paris 6514 of the Bibliothèque Nationale. The fame that the *Book of Secrets* enjoyed in the Latin world is testified by the existence of several Latin copies which were studied and partially edited and translated into German by Ruska.[16]

As anticipated, the truly exceptional character of this alchemical treatise in the context of the contemporary Arabic alchemical production lies in its clear structure, its thoroughness, and the plain language and style in which ingredients, apparatus, and operations are dealt with. In consideration of these features, the *Book of Secrets* attracted praise among early 20th century historians of chemistry, and al-Rāzī became an *ante litteram* hero of the scientific approach to the natural world. Few quotations from secondary literature devoted to the *Book of Secrets* clearly convey the kind of positivistic enthusiasm and–one may point out– "precursorism" with which the alchemical contents of the *Book of Secrets* were received. In their 1927 contribution on the alchemy of the *Book of Secrets,* Stapleton, Azo and Hidayāt Hussain write:

> For the first time in the history of the world we find a systematic classification of carefully observed and verified facts regarding chemical substances, reactions, and apparatus, described in language which is almost entirely free from mysticism and ambiguity.[17]

and on al-Rāzī they write:

> [he] was the most noteworthy intellectual follower of the Greek philosophers of the seventh to the fourth centuries B.C. that mankind produced for 1900 years after the death of Aristotle.[18]

This re-assessment of the chronology of the insurgence of a 'modern' approach to chemistry was a great preoccupation for these historians of alchemy, as stated in the opening of their work:

> Our aims are confined, in the first place, to supporting the thesis that in 900 A.D. such a degree of exact knowledge of chemical substances and apparatus was displayed that historians may henceforward be justified in antedating the birth of scientific Chemistry by – in all probability – at least 900 years.[19]

Gerard Heym, some ten years later, expressed a similar judgement in an article that considered the alchemical ideas conveyed in al-Rāzī's works in the context of the intellectual and religious currents running through the Islamic world in the 10th century:

> al-Rāzī transformed alchemy for the first time into a science based on experiment. That accounts for the great vogue of his alchemical works, especially in the West: it was his scientific approach to the problems of nature that attracted the best minds for 700 years. [20]

Julius Ruska, who partially translated the Arabic original and edited and studied the Latin translations of the work, in consideration of the contents and style of the *Book of Secrets*, defines al-Rāzī as the founder of a new alchemy ("Begründer einer neuer Alchemie") and as the person who "rendered alchemy in a strictly scientific form."[21] In the almost one hundred years that separate us from the research of these pioneers of the history of alchemy in the Islamic world, more evidence has been unearthed and more authors and treatises have been studied. In addition, historians of science have moved away from presentism or teleological narratives that look for a direct line of transmission from an ancient origin. In the field of alchemy, it has been proved that highly allegorical and encoded texts can also convey effective and reproducible alchemical operations while, at time, even the plainest of recipes derived from one of the 'chemical' works of al-Rāzī can present interpretational and technical challenges to the modern reader and the modern chemist.[22]

The treatise that will be analysed and compared with the *Book of Secrets* is the *Book on Alums and Salts*, at times attributed to the same Al-Rāzī, but very likely a spurious work composed in Islamic Spain during the 12th century, and almost immediately translated into Latin. The Arabic original of the *On Alums and Salts* is only represented by a fragmentary copy preserved in a multiple-text manuscript in Berlin's Staatsblibliothek (MS Sprenger 1908, ff. 19r-30 v), which contains neither a specific title page for the treatise nor colophon, and no indications of authorship, copying circumstances and dating are found. The heading for the whole manuscript reads *Kitāb al-jawhar al-naḍīr fī ṣināʿat al-iksīr li Abī ʿAbdallāh al-Ṭuġrā'ī* ("*The Book of the Blooming Gem in the Preparation of the Elixir* by Abū ʿAbdallāh al-Ṭuġrā'ī") which appears to misrepresent the contents and authorship of the manuscript.[23] In the 12th century, the Arabic *On Alums and Salts* attracted the attention of one of the most influential Arabic-Latin translators of the Middle Ages, Gerard of Cremona, who was active in Toledo, Spain, and had already worked on the *Book of Secrets*. Not only did Gerard translate the treatise, he also contributed something else that proved crucial for the future fame of this work: he attributed it to a certain Bubacher Magumet filius Ceceri Arrasi, which is a crude Latin rendition of the name of Muḥammad ibn Zakarīyā al-Rāzī, the author of the aforementioned *Book of Secrets*. The *On Alums and Salts* appears–together with a *Liber divinitatis de LXX*, the first treatise from the *Book of the Seventy* by Jābir ibn Ḥayyān, and an anonymous *Luminis luminum*–among the alchemical works listed in the *Commemoratio librorum*, a catalogue of Gerard's translations compiled by members of his circle, which circulated together with Gerard's *Vita* and *Eulogium*.[24]

We currently know of seven manuscripts of the Latin translation of this work, dating from the 14th and the 15th century,[25] and of a 16th-century printed edition, which appeared as part of the *Compendium Alchemiae* attributed to John of Garland and published in Amsterdam in 1560 by Basilius Johannes Herold.[26] The similarity of style and contents between the *On Alums and Salts* and the *Book of Secrets* must certainly be taken into account as one of the reasons for the misattribution of the former. Moreover, the same two treatises are found together in one of the oldest manuscripts preserving Latin alchemical texts, the so-called 'Codex Speciale' (Biblioteca Comunale di Palermo, MS 4 Qq A 10). Both treatises were described by Isidoro Carini towards the end of the 19th century in an account of the history of occult sciences that is chiefly based on a survey of the contents of the aforementioned Sicilian manuscript.[27]

While the first editor of a Latin version of the *On Alums and Salts,* Robert Steele, considered the treatise as an original work by al-Rāzī, Julius Ruska advanced a series of very sensible objections to the traditional attribution.[28] At the current state of knowledge, Ruska's opinion that the Arabic *On Alums and Salts* is a product of an anonymous Arabic alchemist active in al-Andalus during the 11th-12th century appears as the most plausible. In order to grasp the whole picture of the contents of the *On Alums and Salts* one cannot rely exclusively on the extant Arabic manuscript, from which entire sections of the work are missing. For the aim of this article, I have relied on the contents of the Latin translations, when the Arabic text is not available, and supplemented them with the contents of a peculiar early-modern Hebrew version of the same treatise.[29] This Hebrew version was probably produced in Northern Italy by an alchemist who not only translated from a more complete Arabic *Vorlage* than the one now extant, but also actively intervened in the text and its margin, adding notes, comments, opinions and quotations of other works. In particular, the Hebrew translator appeared to keenly intervene in the content of the alchemical recipes of the *On Alums and Salts* by adding in the text itself; in the margins this same translator inserted a large number of comments and notes that clearly derive from an active practical engagement with the text and are the result of a process of 'practical exegesis'.[30] Alternative quantities, substitute ingredients, and different operations were also introduced in the Hebrew version of the *On Alums and Salts,* giving the clear impression that the Hebrew copyist sought practical, operative applications to the text he was reading.

In all accounts, the *On Alums and Salts* shares with the original *Book of Secrets* a similar approach to alchemical doctrines that points at the laboratory rather than the library and at an alchemical production that, being devoid of allegorical images and complex *Decknamen*, aims at recording laboratory recipes and techniques in the most straightforward (and reproducible) way possible.

It should not surprise us that also the *On Alums and Salts* was considered by the 20th-century historians of chemistry as a precursor of modern positive chemistry. Robert Steele titles his edition of a Latin version of the work "Practical Chemistry in the 12th century" and opens his contribution by stating: "This work, the first known to Western Europe dealing with the preparation of chemical substances for use in subsequent operations, must rank as one of the classics of chemistry and pharmacy".[31] Julius Ruska, who edited the Arabic text and edited and translated the Latin version of the work on the basis of the text found in the aforementioned *Compendium Alchemiae* and a selection of Latin manuscripts, titled his monograph *Das Buch der Alaune und*

Saltze. Ein Grundwerk der spätlateinischen Alchemie, "a basic work of late Latin alchemy", somehow by-passing the Arabic origin of the treatise. In the conclusion of the introduction to his edition, Ruska writes that "the unity and internal uniformity of the work becomes apparent" ("so ist zunächst di Geschlossenheit und innere Einheitlichkeit der Schrift sichtbar geworden") and that "the descriptions of the most important substances are carried out according to a uniform plan and from a uniform understanding" ("die Beschreibungen der wichtigsten Stoffe sind nach einem einheitlichen Plan und aus einer einheitlichen Auffassung heraus durchgeführt"). Ruska stresses the practical interests of the anonymous author and his claims to present truthful recipes and procedures ("Er betont an zahlreichen Stellen die eigene Erfahrung und ermahnt den Leser, sich durch Versuche von der Richtigkeit seiner Angaben zu überzeugen").[32] Based on the present analysis of this section of text, we may conclude that both the *Book of Secrets* and the *On Alums and Salts* were composed and are intended to be read as practical alchemical handbooks, operative guides for the alchemists where substances are organised according to their physical and chemical properties, and recipes are described step-by-step in clear language and plain style, at least if we compare these two works with most of the contemporary alchemical materials in circulation.

CLASSIFYING ALCHEMICAL MATTER

The alchemical operations described in both the *Book of Secrets* and the *On Alums and Salts* rely on a precise classification of the ingredients that enter the alchemical work. These classifications, which are based on the analysis of a specific ingredient's behaviour when exposed to external agents (heating, cooling, compressing, etc.) or combined with other ingredients, are mutually consistent in almost all respects.

In the first section of the *Book of Secrets*, alchemical ingredients *(ʿaqāqīr)* are distinguished as earthy (*barrāniyya*), vegetable (*nabātiyya*) and animal (*ḥayawāniyya*). Earthy substances, that are central in the alchemical work according to Al-Rāzī are of six different kinds: spirits (*arwāḥ*), bodies (*ajsād*), stones (*aḥjār*), vitriols (*zājāt*), boraxes (*bawāriq*), and salts (*amlāḥ*). These six kinds represent the smallest groupings of earthy substances, below which al-Rāzī mentions individual substances. Spirits are mercury (*zi'baq*), sal ammoniac (*nushādir*), sulphur (*kibrīt*) and arsenic (*zarnīkh*); bodies are the seven metals: gold (*dhahab*), silver (*fiḍḍa*), iron (*ḥadīd*), copper (*nuḥās*), tin (*qalāʿī*),[33] lead (*usrub*) and *khārṣīnī*; stones are marcasite (*marqashīshā*), magnesia (*maġnīsiyā*), iron oxide (*daws*), tutty (*tūṭiyā*), lapis lazuli (*lazawārd*), malachite (*dahnaj*), turquoise (*fayrūzaj*), hematite (*shādanj*), arsenic oxide (*shakk*), antimony (*kuḥl*), mica (*ṭalq*), gypsum (*jabsīn*) and glass (*zujāj*); vitriols are black vitriol (*al-aswad*), yellow vitriol (*al-aṣfar*), alum (*shabb*), *qalqand, qalqadīs, qalqaṭār* and *sūrī*; boraxes are bread borax (*bawraq khubzī*), natron (*naṭrūn*), borax of the art (*bawraq al-ṣināʿa*), *tinkār*, borax of *zarāwand*, borax of the West (*bawraq al-ġarb*); salts are good sweet salt (*al-milḥ al-ṭayyib al-ḥulw*), bitter salt (*al-milḥ al-marr*), salt of Andara (*al-milḥ al-andarānī*), salt of *ṭabarzad* , salt of naphtha (*milḥ nafṭī*), Indian salt (*milḥ hindī*), salt of the egg (*milḥ bayḍī*), alkali salt (*milḥ al-qalī*), salt of urine (*milḥ al-bawl*), salt of borax (*milḥ al-nūra*), salt of ashes (*milḥ al-ramād*).[34]

In the *Book of Secrets*, al-Rāzī does not devote much space to vegetable substances, which are discussed in a chapter of the third and final section of the treatise. Al-Rāzī argues that these are of not much interest to the alchemist, apart from the ashes of a plant found in the proximity of swamps called *ushnān*. Substances derived from the animal realm and employed in alchemy are more numerous and relevant: hair, skull, brain, egg, gall, blood, milk, urine, mother of pearl, and horn.[35] Al-Rāzī's account is arguably the most precise description of the contents of the cabinet of a medieval alchemist that has reached us, and shows the clear traces of a tendency towards simplification, organisation, and systematisation that characterises the *Book of Secrets*. Some of the substances mentioned in this classification may require few words of explanation. The list of the seven metals is concluded by the mention the *khārṣīnī*, which is often translated as 'Chinese iron' or as 'Chinese arrowhead' (*al-Ṣīn* is the Arabic for China). Stapleton, Azo and Ḥidāyat Husain devoted some remarks to the identification of *khārṣīnī*, which they considered significant also as a hint to the sources of al-Rāzī's alchemical ideas.[36] In their opinion, the presence of *khārṣīnī* places the origin of al-Rāzī's ideas on metals in Ḥarrān (in modern Turkey), and in particular among its Sabian inhabitants who were heirs of Greek as well as Babylonian technical traditions. They also go as far as hypothesizing possible traces of a connection between the tradition of Chinese alchemy and Islamic alchemy for which, even after almost a century of research, no substantial evidence has been found. Among the different kinds of vitriol, four names are employed for distinguishing the vitriol's colour: *qalqand*–at times also called *qalqant*–indicates green vitriol, *qalqadīs* white vitriol, *qalqaṭār* yellow vitriol and *sūrī* red vitriol, being possibly the Arabic rendition of four Greek terms: *chalcathon*, *chalchitis*, *colocothar* and *sory*.[37] *Tinkār* is a term commonly used for describing either a kind of borax or a kind of salt and is associated with the name *liḥām al-dhahab* in the literature, a phrase sometimes interpreted as referencing chrysocolla.[38] Borax of *zarāwand* refers probably to the plant called in Persian *zarâvand*, the *aristolochia* or birthworth. Salt of Andara refers to the geographical area form where it was customarily obtained: Andara is a village in the province of Kerman (modern Iran); the phrase 'salt of *ṭabarzad*' (Persian: *ṭabar-zad*, 'axe-splitting') possibly refers to coarsely crystalline rock salt.[39]

The *On Alums and Salts* does not offer a classification of alchemical substances in the form of a list, as it is the case with the *Book of Secrets*. Instead, it is possible to retrieve such classification from the structure of the treatise itself, as will be discussed below. For the sake of returning the most complete image possible of the system of understanding of matter in the *On Alums and Salt*, I am going to follow closely the Hebrew translation of the work for the passages where it preserves a more complete version of the treatise, in particular for the large sections that are not found in the only extant Arabic manuscript.[40] In the pseudo-Rāzian treatise, the order in which the different kinds of alchemical ingredients are presented is virtually reversed in comparison to the one found in the *Book of Secrets*: in the extant Arabic and Hebrew versions, the treatise opens with a discourse on vitriol, whose varieties are listed in the Hebrew version as *qolqodor, sūrīn, qalqadīm* and *qalqant* and correspond to the kinds of vitriol mentioned by the genuine al-Rāzī. The section on alum, regardless of the title of the treatise, is very brief, while an extensive treatment is devoted to salts. Among salts, rock salt, bread salt, Indian salt, salt of lime, bitter salt, sal ammoniac and alkali salt are mentioned. It is particularly significant to highlight the different position of sal ammoniac (*nushādir*), which is classified as a 'spirit' in the *Book of Secrets* and here, instead, as a salt. The discrepancy between the two treatises on the classification of sal ammoniac was considered by Ruska as one of the hints pointing at a pseudo-epigraphical origin of the *On Alums and Salts*. It must anyway be noticed that sal ammoniac is similarly mentioned among salts in another undoubtedly original work by al-Rāzī, the aforementioned *Al-Madkhal al-Taʿlīmī* ('The instructive introduction'), one of the *Twelve Books*.[41] Given the different contexts in which sal ammoniac is mentioned, the *On Alums and Salts* lists only three kinds of spirits: arsenic (of which only the yellow kind is considered), sulphur and mercury. In accordance with the contemporary theory of metallogenesis, mercury is praised as the basic constituent of all minerals and as their 'ferment', i.e. the agent that activates the alchemical transmutation and that is generally able to perform marvelous actions when combined with metals:

> God created all the minerals from it, and for this [reason] it is their birth […] it makes great, marvellous and praiseworthy actions. It alone is the living spirit. In the world, there is nothing like it that can perform what it can perform. It penetrates all the bodies […] For this reason, when it is mixed with any of all the bodies, it vivifies it, enlightens it, and makes it change from one state to another and from one shape to another. When it is mixed with it, it is the ferment of that body […] Then it is the complete elixir for the white and for the red. It is the eternal water, the water of life, the milk of the virgin, the herb that purifies and washes, the source of life, because he who drinks from it will live and will never die.[42]

Among the 'bodies' (i.e. metals, Hebr. *gufot*), the Pseudo-Rāzī mentions gold, silver, iron, copper, tin (in its two varieties *al-ūqī* and *al-qalaʿī*) and lead.[43] The positioning of mercury among spirits and the absence of *khārṣīnī* from this list brings the number of metals discussed in the *On Alums and Salts* down to only six, in a rather non-traditional fashion. The treatise is concluded by few chapters on glass and on the production of artificially coloured gemstones (red, azure and green).

Both the *Book of Secrets* and the *On Alums and Salts* are organised around a clear classification of matter in which alchemical ingredients are distinguished according to their physical features. These features, derived from the material composition of their substance, are instrumental for the definition of the alchemical operations that need to be performed on the various ingredients mentioned in order to purify them and make them suitable to enter the final steps of the alchemical transmutation, the production of silver and/or gold. In this respect, both treatises stem from these classificatory schemes and appear to derive the sequence of recipes that they encompass as a direct consequence of such considerations and distinctions.

COMPOSING AN ALCHEMICAL BOOK

While the range of ingredients mentioned and classified in the *Book of Secrets* and in the *On Alums and Salts* overlaps almost completely, the structure of the two treatises differs in a significant manner. While both treatises show a remarkable operative aim and tone, and consistently share a similar plainness of language and stylistic restraint – a feature that was highlighted and appreciated by 20th century historians of chemistry – the ways in which they expound alchemical recipes and trace the *cursus* of the alchemical work diverge.

The *Book of Secrets* opens with the aforementioned classification of substances that enter the alchemical work. The following section encompasses the description of derivative substances (*al-ʿaqāqīr al-muwallada*), which are artificial substances derived from the basic ingredients listed in the first section. Here we find mention, for instance, of white lead (*isfīdāj*), verdigris (*zinjār*), and of various metallic oxides. The *Book of Secrets* devotes a short section to alchemical instruments: apparatus for melting metals include bellows (*minfakh*), crucibles (*būṭaqa*), the double-crucible (*būṭ bar būṭ*, from which the Latin *botum barbatum*) and ladle (*miġrafa*); apparatus for the manipulation of substances more in general include cucurbit (*qarʿ*), alembic (*inbīq*), blind alembic (*al-inbīq dhāt al-khatm*), receiving vessel (*qābila*), tongs (*māsik*), hammer (*mukassir*), etc. The treatise here reveals its organising structure: the section on alchemical operations employs single operations as headings and describes how each operation must be adapted and planned in order to be applied fruitfully to a specific ingredient.[44] The organisational unit in this section is the single operation, which is adapted to the substance that constitutes its main ingredient, and not a particular ingredient or goal. A clear aim of systematisation can be detected in the lines of the *Book of Secrets*: it appears that al-Rāzī worked at organising in a logical and operative structure the shapeless materials he derived from the reading of previous alchemical works and from laboratory observation. The operations described in the *Book of Secrets* are distillation (*taqṭīr*), sublimation (*taṣʿīd*), descension (*istinzāl*), assation or roasting (*tashwiya*), cooking (*ṭabkh*), amalgamation (*talġīm*), lavation (*ġasl*), calcination (*taklīs*), and ceration (*tashmīʿ*). For instance, details of the operation of distillation differ depending on the main ingredients the alchemist wants to distil. The *Book of Secrets* thoroughly describes several operations of distillation for the following starting ingredients: mercury (twelve recipes), sal ammoniac (five recipes), and sulphur (eleven recipes). The operation of calcination can be performed in three ways, through burning (*taklīs bi-al-ḥaraq*), through the action of rust (*taṣdiya*) or through amalgamation (*talġīm*). The treatise details how to perform the three kinds of calcination on gold, silver, copper, iron, lead and tin; al-Rāzī provides further operative notes on the calcination of marcasite, magnesia, tutia, lapis lazuli, malachite, turquoise, hematite, antimony, and talc. Overall, the *Book of Secrets* places at its centre of interest alchemical operations, and appears to emphasize the ways in which each alchemical operation is adapted according to the ingredients involved in it.

*On Alums and Salt*s, on the other hand, employs a different organisational principle: here, the work focuses on single ingredients. Lacking the list of alchemical materials that features in the *Book of Secrets,* the *On Alums and Salts* deals with each substance within dedicated sections, each of which constitutes an individual treatise that can be read as an independent textual unit providing all the information needed on a specific substance. Therefore, for every ingredient under discussion, the Pseudo-Rāzī offers a description of its qualities, physical features, connection with celestial bodies (in the case of metals) and relevance to alchemists who intend to use it. Very frequently, the procedures described are the preliminary steps to prepare ingredients that may be used in other successive operations, thus creating a logical sequence whereby the final product of one prescription often becomes the starting material for the next.

Similar in their contents, but different in their structure, the authentic and the spurious Razian treatises discussed above present two equally effective strategies of transmitting the practicalities of the alchemical work in plain language, consequential steps, and in a firmly structured discourse. While the *Book of Secrets* focusses on the operations and how they apply to the different ingredients, the *On Alums and Salts* is centred around the ingredients, which are dealt with exhaustively in separate and self-conclusive sections. What appears to be clear from the extant manuscript evidence is that both treatises managed to attract the attention of readers, translators and copyists, be it for the fame of their author or for the intrinsic perceived usefulness of their contents.

CONCLUSIONS: AUTHORITY, STRUCTURE, AND PRACTICE IN MEDIEVAL ALCHEMY

The circulation of the *Book of Secrets* and of the *On Alums and Salts* was surely fostered by their genuine or spurious association with the name of Muḥammad ibn Zakarīya al-Rāzī, an authoritative figure connected to medical "best-sellers," that circulated widely in Arabic language and Latin translation. It appears, in any case, that at least for the *On Alums and Salts* the connection with the Persian polymath was not the main incentive for its fame. If we examine the extant manuscripts of the *On Alums and Salts* in Arabic, Latin and Hebrew, the evidence may reveal the shortcomings of the argument for authority or, at least, may hint at the need for further analysis. Among the nine manuscripts (the two Arabic and Hebrew *codices unici* and the seven Latin manuscripts), only the Latin Parisian manuscript (MS 6514, Paris, Bibliothèque Nationale), the one that possibly derives from the translation by Gerard of Cremona, transmits the name of al-Rāzī as the author of the treatise. The Arabic, the Hebrew and the other Latin versions are silent on the authorship of the work or, at times, offer indication of different names. For example, the Latin manuscript in the Biblioteca Comunale of Palermo on the side of the traditional title *Sermo de aluminibus et salibus, quae in haec arte necessaria existunt* ("The *Book on Alums and Salts* that are needed in this art") records another title and attribution: *alii intitulant hunc ita Incipit Liber Ypocratis et Galieni* ("others call it «Here begins *The Book of Hippocrates and Galen*»").[45] Since the largest part of the tradition of this treatise is anonymous, the reason of the fame of this work must be found outside the influence of its pseudo-epigraphic attribution.

Scholarship on the production and transmission of European medical treatises between the XIII and the XIV century has shown that early collections of medical recipes and remedies derived their authoritativeness not only from the names of their compilers–which, in the case of single recipes was often unknown or not explicit –but also from their organising criteria and structure. These treatises offered a sound structure that also enhanced the didactic value of a work; this was the discriminant between a random accumulation of medical (or alchemical) recipes and a medical *Summa*, like the one composed by Guglielmo da Saliceto (XIII c.) or, alternatively, a medical *Thesaurus,* like the one compiled by Petrus Hispanus (XIII c.) as a medical handbook for the poor.[46] When we consider the way in which alchemical recipes are organised as a logical progression and as a direct application of the theoretical points that are made explicit at the beginning of each section of the *On Alums and Salts*, we may see a similar phenomenon: the *On Alums and Salts* may derive its *auctoritas* and its fame as an alchemical treatise from the strength of its internal structure, a structure that, together with the plainness of exposition and language, made this treatise readable in the library and useful in the laboratory. The fact that the *On Alums and Salts* was employed as an operative handbook is clearly shown by the only extant Hebrew version of the treatise. Its translator or copyist did not limit himself to rendering the treatise in Hebrew language, but intervened heavily on the work, adding comments, variants, and notes both in the main text and on the margins of the manuscript. These additions – often placed between brackets and frequently introduced by the Hebrew abbreviations *n´´l* (for *nireh li*, "it seems to me") and *s´´'* (for *sevarah aḥeret*, "another explanation") – tend to suggest modifications of the recipes of the *On Alums and Salts*, proposing the substitution of ingredients, variations in their quantities and different operative steps.[47]

The practical character of these additions and notes (in italics in the excerpts) can be appreciated, for instance, in the passage describing the operation for the congealment of mercury, where the Jewish copyist intervenes a first time describing the colour of a partial product of the operation and a second time correcting the main text:

> The congealment with sulphur is that you take three ounces of sesame oil, if you find [it] or, if not, olive oil. Boil it on fire in a glass vessel and, after this, put with it slowly half an ounce of pulverised yellow sulphur, and grind it with the oil until it dissolves. I tried it and I dissolved it all. Then take it out on top of the fire and let it rest to cool in [it] – *in my opinion: you should do it like this and it will be as white as lead*. Then put with it one ounce of mercury, place the pot on a gentle fire, and increase it slowly and little by little. Let it rest until it congeals, since mercury will congeal to a red stone – *in my opinion: white*. If not, put in it the element of fire. Then conceal it, save it, rejoice and put [some] of it in all your operations.[48]

Another example can be seen in a passage describing alchemical operations on lead, where the additions of the Jewish copyist are aimed at specifying the chromatic consequences of the use of different ingredients and at clarifying the quantity of salt to be used in this recipe:

> Take the one you prefer between lead or tin and melt it in an iron ladle. Feed every pound of it with one ounce of sulphur – *in my opinion: for red* – or one ounce of arsenic – *in my opinion: for white*. Stir it with a stick until in one hour it looks suddenly like dark ash. After that, grind it in – *in my opinion: the same amount of* – roasted salt dissolved in sharp vinegar and, when it has absorbed it all, put it in a glass pan that withstands fire and light a fire under it for ten hours until white calx comes out.[49]

There is no doubt that the *On Alums and Salts* was read, at least by this early modern Jewish reader, as a practical handbook for the chemical laboratory.

The *Kitāb al-Asrār* and the *On Alums and Salts* represent two accomplished examples of alchemical works that travelled between different geographical, cultural, religious, and linguistic contexts thanks to the appeal of their contents and structure. Contemporary alchemical works of Arabic origin and those produced in medieval Europe engaged readers in an exegetical exercise, in particular when their alchemical contents were concealed under imaginative and allegorical descriptions and obfuscated by the use of *Decknamen*. In the case of the *Book of Secrets* and of the *On Alums and salts,* which are devoid of such intricacies, the exegesis required was of a practical kind, an exegesis that was arguably conducted between library and laboratory.[50]

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43 On the distinction between tin and lead and the different kinds of tin, see Käs, ref. 33, I, 222-23.
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Feature Articles

Between Research and Responsibility: The Invention of Dynamite

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Abstract. The myth surrounding the creation of The Nobel Prize and an incorrectly published newspaper article has long dominated the conversation about the famed inventor Alfred Nobel. In actuality, this myth appears to have been fabricated by biographers. Nobel had a complicated relationship with views on scientific progress; he long contemplated the role of researchers and morality in the face of scientific advancement. He was not the sole contributor to his discoveries; many researchers played a role in the inevitable discovery of the explosive material dynamite. Their stories, combined with the musings of Nobel discussing his explosives empire, provide an interesting insight into the ethics surrounding inventions of destructive materials. Many scientists have claimed their discovery will be the one to end all wars. Can we justify destruction in the name of deterrence?

Keywords: History/Philosophy, Chemical History, Misconceptions, Ethics, Undergraduate Research

DEATH BEFORE DEATH

The myth surrounding the creation of the Nobel Prize is fascinating. It goes as follows. In 1888, a local French newspaper mistakenly assumed dead the famed inventor of dynamite, Alfred Nobel. Instead, his brother Ludvig had died recently of a heart attack, but the newspaper, assuming the death of the elder Nobel, published an article with the attached scathing headline: "The Merchant of Death is Dead." [1] The cruel obituary included in this article stated that Nobel had gotten rich by developing new ways to "mutilate and kill." The article also included multiple references to Nobel as a "merchant of death" due to his creation, production, and fortune gained from the explosive material dynamite.[2] The myth is that Nobel was distraught by what his legacy may become upon seeing this headline and article. Purportedly, this induced him to change his final will and testament, establishing what we still know today as the Nobel Prize, which went into effect after his death in 1896. Upon further examination, this oversimplification of Nobel's character does not appear to be true.

This is the story that was circulated by famed Nobel biographer Nicholas Halasz in his 1959 book, "Nobel: a Biography." [3] Prior to this text, the use of the moniker "Merchant of Death" does not appear to be widespread. After its use for Ludwig in 1888, there are few spikes in usage involving the term, and I find it extremely unlikely that its use was the core determinant of Nobel's decision.

This is not the only biography that purports this tale. In 1991, Swedish actor and director Kenne Fant wrote "Alfred Nobel: A Biography," his book also pointed to the article as the reason for Nobel's peace prizes.[4] Since these two biographies, the myth has become widespread, as even the Nobel Foundation and the Smithsonian have supported the fib. Alfred Nobel's physique and thoughts surrounding his creations appear very different from these fabrications. He was a complicated man, and notes to friends suggest his inward notions as much different from those suggested.

In fact, there is evidence that the article was titled something different and less scathing: "A man who can not very easily pass for a benefactor of humanity died yesterday in Cannes. It is Mr. Nobel, inventor of dynamite. Nobel was Swedish." [5] There has been no record found of the original newspaper claimed by The Nobel Foundation: *Ideotie Quotidienne* (or Daily Nonsense). Instead, the quote I provided was published by a different French newspaper: *Le Figaro*. There is a record of a premature obituary in this newspaper, although its contents do not appear scathing enough to have drastically affected Nobel.[3] Nobel also had an extremely tumultuous relationship with the French press, and something of this nature wouldn't have come close to surprising him.[6]

In short, this story is most likely fabricated. Even if it were true, Nobel would not have acted as dramatically as changing his entire will in response to a newspaper blurb. He believed his weapons were saving the world and is quoted as saying the following to a close friend: "Perhaps my factories will put an end to war even sooner than your Congresses; on the day when two army corps may mutually annihilate each other in a second, probably all civilized nations will recoil with horror and disband their troops." This quote from Nobel not only foretold nuclear weapons of the next 50-60 years but also demonstrates Nobel's emphasis on weapons technology for the goal of peace. Nobel believed his weapons could help the world, and following this narrative of "The Merchant of Death" feels counterintuitive to those goals. In fact, it is far more likely that the peace conferences Nobel attended later in life were the main contributions to his change of heart. His interactions with Bertha von Suttner, a peace advocate and writer, suggest Nobel's change of heart was long determined and could also be a result of some ingrained socialist ideals.[7] These included his disdain for familial inheritances and his value for peace in an ideal world, with deterrence as a best-case replacement. This decision does not appear to be instantaneous but long deliberated over.

Nobel's decision most likely centered around the previously mentioned Bertha von Suttner. Before she married her previous lover, Nobel and Bertha worked together for 8 days. It is contentious whether Nobel was romantically involved with Suttner, but either way, the two were deeply connected. Their correspondence lasted years and involved many philosophical and ethical discussions regarding peace.[8] Suttner was referred to as "the generalissimo of the peace movement," and founded the Austrian Peace Society in 1891.[9] In fact, Nobel has quoted evidence from before the founding of the prizes backing this claim. Nobel said the following to Suttner: "Inform me, convince me, and then I will do something great for this movement." [9] Suttner was given the first Nobel Prize for Peace, awarded in 1905.

The Nobel Prize is the most famous scientific prize given out annually. Monetary awards are given out yearly to those with exceptional achievements in physics, chemistry, physiology or medicine, literature, and peace.[10] The prize for achievements in economics is also awarded yearly, added in 1969. This additional prize is based upon a donation received from the National Bank of Sweden.[11] There was controversy surrounding the creation of the initial Nobel Prize categories. Many members of the Nobel family were upset upon receiving smaller portions of the Nobel fortune and fought legally to overturn the changes to Alfred Nobel's will. In addition, there was a public uproar in Scandinavia over a lack of a Scandinavian nationality requirement for the Nobel Prize. It took five years, but eventually, an independent Nobel Prize foundation was created, and the first awards were given out in 1901.[12] They have been given out annually after that. The Nobel Prize has since become one of the most coveted scientific prizes.

THE SCIENTIFIC PREDECESSORS OF NOBEL

As is the case with most scientific advances, the discovery of dynamite included many contributions from different scientific actors prior to its eventual perfection by Nobel. Figure 1 shows the initial discovery dates for the important milestones involving dynamite. First mentioned is Henri Braconnot, a professor of Botany at the University of Nancy in France. Braconnot practiced pharmacy, chemistry, and botany throughout his professional career. He served as his town's botanical garden director and was also a member of the town's scientific academy.[13] Bracconot discovered a material that he

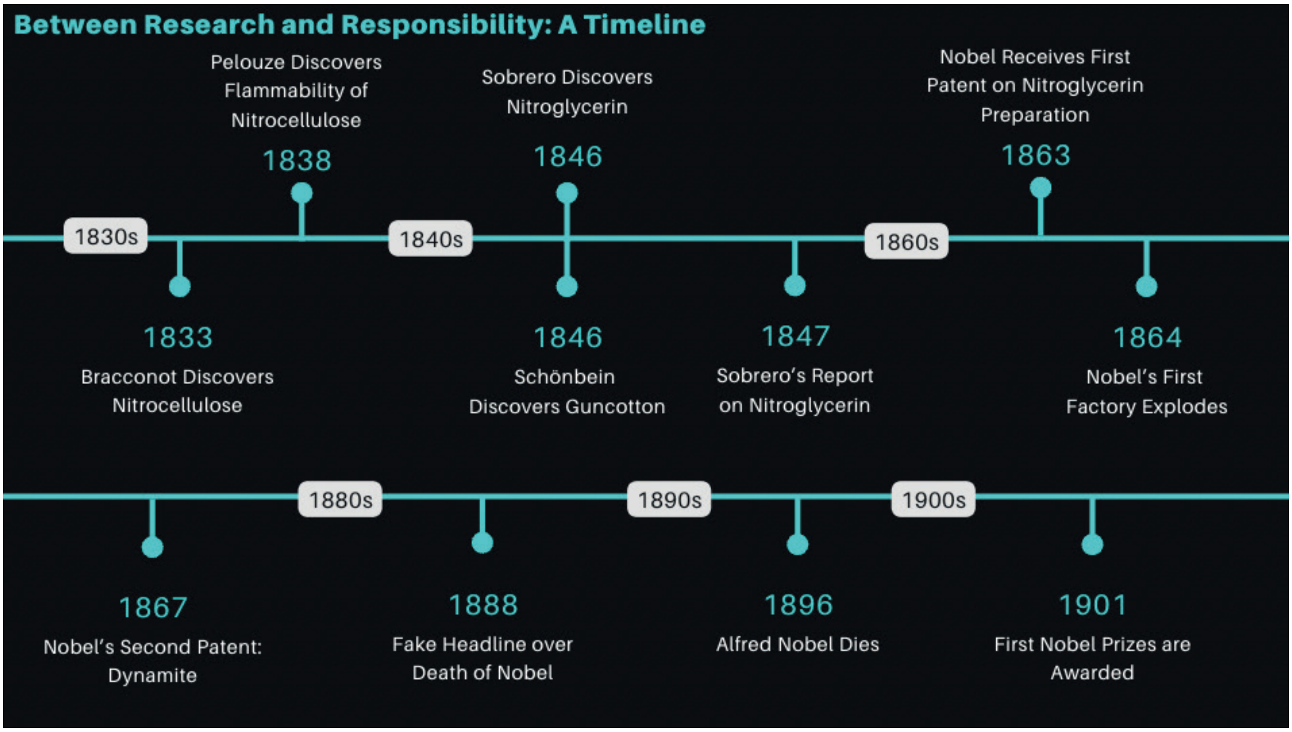

Figure 1. A timeline describing the scientific discoveries that led to Nobel's ultimate discovery of dynamite. Created using Canva

called xyloïdine, now more commonly known as nitrocellulose. He made his discovery in 1833 by combining concentrated nitric acid with starch or various wooden materials. At the time of the discovery, Braconnot did not realize the substance's explosive potential and only noted that it caught fire quickly. Braconnot attempted to make coatings and films with the substance but found little success overall.[14] His discovery received little public recognition due to its limited use cases. Little did Braconnot know, this substance had extremely explosive potential, which would slowly be realized by those scientists who succeeded him.

In 1838, chemist Théophile Pelouze picked up where Braconnot had left off and attempted to create practical uses of these new explosive materials derived from nitrocellulose. Pelouze is most famous for his laboratory, which performed various explosive-based experiments, and eventually included students such as Alfred Nobel. He also held positions at institutions, including *Collége de France* and *Commission des Monnaies*,

Figure 2. Portrait of Théophile Pelouze. Image credit: https://picryl.com/media/theophile-jules-pelouze-chimiste-e453c6. This image is taken from the public domain.

although he resigned from these positions in 1851 after the coup d'état. He continued working in his laboratory long after his professional career had ended and housed many students, including the likes of Alfred Nobel and another explosives scientist, Ascanio Sobrero.[15] Pelouze attempted to submerge materials such as paper, cotton, or tissues in a cold solution of concentrated nitric acid. This process produced a resultant parchment-like material that Pelouze found to be highly flammable. Pelouze's research process was more complicated than Braconnot's. Pelouze reacted a mixture of starch and concentrated nitric acid until the starch had been fully removed with no disengagement of gas from the reaction. The resultant substance was liquid, retaining the yellowish tint of concentrated nitric acid. Pelouze then applied water to the substance and used mechanical filtering and evaporation processes to remove the solid substance, nitrocellulose.[13] Pelouze described the material as "a white non-crystalline deliquescent solid, weighing much more than the original starch." After his experiments, Pelouze believed that this material could be used in artillery, but he personally found no significant use cases for the substance.[13] If it weren't for a congruent discovery made in 1846, xyloïdine, Pelouze, and Braconnot's research could have been lost in the depths of history.

Swiss chemist Christian Fredrich Schönbein revolutionized the explosives world in 1846. More famed for his discovery of ozone, Schönbein wrote to scientists worldwide that he had successfully converted cotton into a material more destructive than gunpowder. He did not immediately reveal the process publicly.[16] This material was later named guncotton, or among chemists, nitrocellulose. Schönbein eventually announced the process publicly, but even before it was revealed, many scientists immediately connected this discovery to the chemical properties of xyloïdine and Pelouze's material. Schönbein accomplished this feat by immersing cotton in a mixture of nitric and sulfuric acid, later washing the product to remove any excess acid that had not fully reacted. There was a good deal of communication between Schönbein and others inquiring about his discovery, and he pointed them toward the works of both Braconnot and Pelouze. This led to the release of a short historical note by Pelouze, which clarified both his and Braconnot's findings to preserve historical accuracy. In this report, Pelouze states that he believes the explosive capabilities of this new material are four times greater than that of gunpowder. He also concludes with the statement that a similar experiment conducted by Flores, Domonte, and Ménard had reacted gaseous nitric acid with mannitol in addition to different kinds of sugars and gums, producing a substance similar to that created with starch in Braconnot's earlier experiment.[13] A professor of chemistry at the University of Turin, Ascanio Sobrero, takes specific note of this concluding remark and writes to Pelouze. Eventually, this earned him a position in Pelouze's lab. Short of Alfred Nobel, no researcher is as essential to the discovery of dynamite as Ascanio Sobrero.

Figure 3. Portrait of Ascanio Sobrero. Image source: https://commons.wikimedia.org/wiki/File:Ascanio_Sobrero.jpg. Image is currently in the public domain

Ascanio Sobrero was born in 1812 in Italy to a wealthy academic family. Figure 3 portrays Sobrero. His father was the secretary of the Royal University of Turin, and Sobrero grew up with a strong focus on academics and the sciences. In 1833, Sobrero graduated from the Royal College of Casale Monferrato with degrees in medicine and surgery.[17] For his graduate studies, Sobrero struggled to choose between medicine and the hard sciences. He obtained his medical license the following year, but he was slowly convinced toward chemistry by his uncle Carlo Raffaello, a general of artillery and the director of the chemical lab of the Arsenal of Turin. Eventually, by 1845, Sobrero had decided to dedicate his talents entirely to chemistry. He accepted a job as a professor of chemistry at the University of Turin, and shortly after, he wrote the above-mentioned letter to Théophile Pelouze.[18]

Upon receiving this letter from Sobrero, Théophile Pelouze invited the young chemist to his explosives-centered laboratory. In this lab, Pelouze experimented primarily with guncotton and other nitrosulphates. We previously described his submersion of parchment or cardboard in concentrated nitric acid, but, in addition, Pelouze executed a variety of experiments to explore the newly expanding explosives field. He also conducted many experiments involving research into salicin, beet-root sugar, and their effects on various organic acids, nitrosulphates, and glass composition.[15] Despite this, Pelouze never made any personal discovery of note. Instead, his historical relevance comes from his influence on his two most famous students, Ascanio Sobrero and Alfred Nobel.

Sobrero did not make his most famous discoveries while working in Pelouze's laboratory, but it is clear that some influence occurred based on the research material. While studying with Pelouze, Sobrero did various experiments involving guncotton, combining it with different materials in an attempt to produce useful resultant products. His tenure in the laboratory lasted less than a year, and when he returned to Italy, he soon made his most famous discovery of his career: nitroglycerin.[19] Sobrero emphasizes that the discovery occurred after his tenure in the laboratory, purely on Italian soil. The process he used to create this material is reminiscent of the experiments conducted by Pelouze and Braconnot before him.[18]

Sobrero created nitroglycerin by stirring drops of glycerin into a cooled mixture of nitric and sulfuric acids. He initially named the substance 'pyroglycerine', and, unlike the procedures discussed for nitrocellulose, this resultant material was oily instead of solid.[13] Upon its discovery, Sobrero conducted many tests on the substance. The most famous involved heating a drop of the substance in a test tube which exploded, permanently scarring his face. Eventually, Sobrero deemed the substance too destructive and volatile for practical use. He feared the implications of the commercialization of nitroglycerin. He was quoted to have said later in a communication to the University of Turin, "When I think of all the victims killed during nitroglycerin explosions, and the terrible havoc that has been wreaked, which in all probability will continue to occur in the future, I am almost ashamed to admit to be its discoverer."[19] Initially, after discovering nitroglycerin, Sobrero kept his findings secret for over a year. Yet, with the popularity of Schönbein's research on guncotton, he knew that it would be impossible to hide forever. He released his studies on nitroglycerin in 1847.[20] Shortly after that, engineers worldwide envisioned its practical and deadly applications.

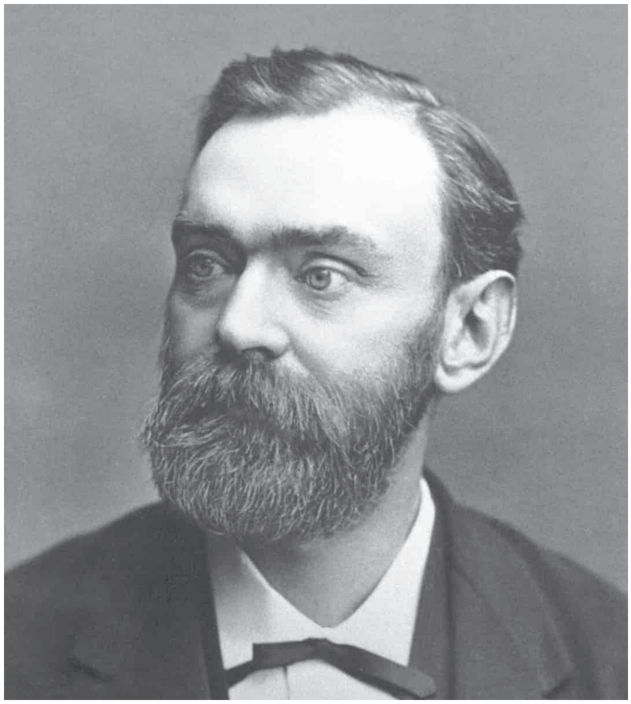

Figure 4. Portrait of Alfred Nobel. Image Source: https://snl.no/Alfred_Nobel. Image is taken from the public domain.

THE EMPIRE AND CREATIONS OF ALFRED NOBEL

Due to his work with explosive substances, Alfred Nobel was able to prosper from the nightmare of Ascanio Sobrero. His ability to neutralize nitroglycerin was critical in the discovery of dynamite, an extremely explosive substance. Nobel succeeded because of his unique traits - a combination of research prowess, organizational talent, and entrepreneurship. Nobel's upbringing was modest and the situations surrounding him as a child never suggested the explosive empire he would one day create. In fact, the majority of his discoveries resulted from desperate attempts at saving his family from bankruptcy. Additionally, long into his career, Nobel constantly contemplated the effects of his research with close friends and relatives. He was obsessed with the societal effects resulting from scientific research and was insistent that the creation of a large enough weapon would permanently end all wars. He is quoted as saying: "I wish I could produce a substance or a machine… of such frightful efficacy for the wholesale devastation that wars should thereby become altogether impossible."[21] This is a notion shared by many inventors, specifically pertaining to the creation of inventions with possible ill intent.

Alfred Nobel was born in Sweden in 1833, but he soon moved to Russia at the age of nine in 1842. Alfred Nobel was the son of a man who supplied war material to the Russian military. Nobel's father was an eccentric personality and an inventor. He began as a building constructor and contractor in Stockholm. He very soon began building beyond his capabilities and fled to Russian-ruled Finland in 1837 after going bankrupt. His wife and two sons joined him five years later, in 1842.

While working in Finland, Nobel's father, Immanuel Nobel, produced wagon wheels, steam hammers, and other mechanical tools. His interests quickly shifted to explosive mines, bought up by the Russian military in bulk at the onslaught of the Crimean War.[22]

During the Crimean War, the Nobel family business was highly profitable. In 1851, when Nobel was 18, Immanuel Nobel could afford to send Alfred to Pelouze's lab, where he studied guncotton and Sobrero's nitroglycerin. After this, he briefly apprenticed with an inventor in New York. These few years abroad proved vital to the development of Alfred's chemical engineering skills. Upon returning home to Russia, the war had ended, and so had his father's period of profitability.[23] The family desperately searched for new solutions for more efficient construction, eventually moving the entire family back to Sweden. Here, Nobel turned his attention on nitroglycerin, which he had previously studied in Pelouze's lab.

Nitroglycerin was known to be highly explosive, and engineers envisioned uses for many different industries, including construction, terraforming, and weapons. Its problem was its stabilization, as the material was extremely volatile, and mass-scale production would be impossible to carry out safely. Nobel began experimenting with the material around 1860, a year after his father's company had declared bankruptcy.[24] He had been trained as a chemical engineer and had experience from his time in Pelouze's lab and his additional apprenticeship. After securing financial support, Nobel opened up his own laboratory for testing explosive materials. The goal was to develop a series of more reliable explosives for consumer and military use. Unfortunately, in 1864, his factory exploded due to a nitroglycerin reaction, killing his brother Emil in the process. The local authorities barred Alfred from experimenting with nitroglycerin inside city limits, and he had to take his research to a barge on a lake outside of town.[25] He was also mandated to work alone, and he began overseeing all aspects of his operation.[22] The surroundings of this factory would eventually expand into Nobel's explosives empire, but its beginnings were humble. With a new laboratory in hand, Nobel's goal became simple, develop a safe method for dealing with and producing nitroglycerin-based explosives. His dedication has to be envied, specifically after such a tragic death due to his own research.

Nobel spent the following years perfecting the nitroglycerin-based explosive. His research began with some of the first detonators and blaster caps as safer mechanisms for explosions. Previously, in attempted explosions utilizing nitroglycerin and gunpowder, a tube of nitroglycerin was inserted into a large tube of gunpowder to create the explosive effect. Nobel's method was different. He inserted a small tube of gunpowder with an attached fuse into a larger tube of nitroglycerin. This is Nobel's "Patent Detonator," the invention that kickstarted his explosives career.[22] This entire mechanism could then be placed inside of an iron pipe filled to the brim with nitroglycerin. A small "cap," or the included gunpowder, ignited the remaining explosive material.[26]

Nobel then turned his attention to safer mechanisms for the transport of the explosive material. His use of kieselguhr (clay) is most notable, stabilizing the explosive when mixed with liquid nitroglycerin. Nobel molded rods and cylinders using kieselguhr, which he refined into the explosive material dynamite using his patent detonator design.[23] Dynamite is formed by submerging blasting oil into kieselguhr. Dynamite could be safely handled and transported en masse, and then instantaneously exploded on site when desired. Blasting caps could also be removed for transport. With the use of kieselguhr and newly invented blasting caps, the safe, mass transport of explosive material proved possible.[22]

Prior to Nobel's innovations, the idea of nitroglycerin-based explosions proved attractive to many. Unfortunately, their volatility caused an array of accidents. I previously mentioned the Nobel factory explosion in 1864. There are numerous other examples of unintentional explosions occurring due to nitroglycerin. Examples include accidents in New York, Panama, San Francisco, Australia, Germany, and Belgium. These accidents created public fear surrounding nitroglycerin-based explosives and their use, even after safer mechanisms for transport and use had been developed. At this time, Nobel's role shifted from scientist to salesman. He traveled from country to country, pitching construction firms and militaries alike, all while building factory upon factory on the way. Nobel patented Dynamite in 1867, a year in which he produced 11 tons of the material. By 1874, the production had risen to 3,120 tons produced annually.[22]

The discovery of dynamite ultimately led to the chief product of Nobel's legacy, his company, and his fortune. He continued to produce blaster caps and also invented gelignite, a more stable nitroglycerin-based explosive. His final invention of note is ballistite, a safer and more explosive material created from a combination of nitroglycerin and nitrocellulose. Ballistite is a propellant explosive and was noteworthy in the production of ammunition.[22]

Over the following years, Alfred Nobel patented these discoveries in Sweden, the UK, and the US. Eventually, he amassed 355 patents worldwide and, adjusted to today's dollars, over 160 million dollars to his name when he passed in 1896.[27] His company had over 100 active factories producing nitroglycerin-based explosives at his death.

Nobel was an extremely successful scientist and entrepreneur, harnessing a chemical discovery that preceded him by almost twenty years. His inventions proved capable of supporting multiple wars while also revolutionizing the construction industry. Production of dynamite was imminent. In less than ten years after its discovery, Nobel's factories produced over 5000 tons of dynamite annually.[28] This empire only expanded. By the early 1940s, long after his death, Nobel's explosives campus had grown to over 700 buildings, mostly in Germany. Much of this was destroyed during World War II by the British. In the 1970s, a nuclear plant was built on the location, but it was shut down in 2011. Today, Nobel's empire and the land it sat on stand empty.[28] All that remains are small remnants for tourism purposes, including a guesthouse. Figure 5 displays the nuclear power plant, now dormant for over a decade.

A large remaining part of Nobel's legacy also lies in the prize, which was created in his will. Annual prizes are given out to outstanding discoveries in the fields of physics, chemistry, physiology or medicine, literature, peace, and economics. Prizes include a generous cash payment. In addition, the Nobel Prize Foundation has gained significant prestige since Alfred Nobel's passing. It is the most significant scientific honor. It is probably the most famous remaining occurrence of the namesake of Alfred Nobel. Its origin is disputed, but I believe his decision to create the prize was the result of a long-standing deliberation, and not an instantaneous knee-jerk reaction to an incorrectly written newspaper article. Without the Nobel Prize, the discoveries of Nobel may have been left in the annals of history.

Figure 5. Picture of the Krümmel Nuclear Power Plant, which occupies the former real estate of part of Nobel's explosives empire in Germany. Image source: https://commons.wikimedia.org/wiki/File:Kernkraftwerk_Kruemmel_Back.jpg. Image taken from the public domain.

WHO ARE YOU, ALFRED NOBEL?

Dynamite has had both positive and negative effects on today's world. Although Alfred Nobel can be referred to as a "Merchant of Death," he could also be described as a merchant of transportation, modern infrastructure, and many other aspects of modern living. Dynamite, although most famous for its use in wartime in weapons such as cannons, bombs, missiles, and simple handheld explosives, transformed the railroad industry in the late 19th century.[29] Previously, workers had to mine through mountains or tediously build long bypasses. Now, they could safely and efficiently blow a hole straight through the middle of an obstacle. In the U.S, railroad tunnels spread nationwide, while projects like Mount Rushmore became possible.[30] Tunnels were dug through hard-to-pass mountain ranges, such as the Alps. Canals like the Panama and Suez Canal were also constructed, aiding international transport.[29]

In addition, natural resource collection, including rare earth metals and other natural resources, became easier to collect. Although they did not quite exist in Nobel's time, dynamite has also helped provide the components for the mass production of modern-day electronics and other products required for our technological progress. In addition, dynamite is often used for the mass mining of coal, which powers much of our society's energy consumption. The discovery of dynamite facilitated many aspects of our world that we enjoy but inevitably also led to destruction.[31]

Nobel's discoveries increased the ferocity of warfare. The invention of dynamite caused further advancement in various designs for bombs, grenades, and mines.[32] Ballistite also helped create various innovations in artillery and ammunition.[22] Shortly after Nobel's death, between 6 and 7.5 million individuals died in World War One as a result of heavy machinery, poison gas, and small artillery in warfare.[33] Although these losses cannot be individually attributed to Nobel, it is undeniable that many of Nobel's innovations in military technology led to higher death counts in warfare.

Many modern derivatives of Nobel's inventions are currently banned weapons of warfare. Without international regulation, they could prove extremely dangerous. Sometimes, they still do. Examples of these weapons include cluster bombs, land mines, and booby traps.[34] In addition, other modern explosives utilize designs created and patented by Nobel. Plastic explosives and other explosive mechanisms still use blaster caps and the overall detonator design. Modern detonators are more sophisticated, utilizing precisely applied waveforms to achieve detonation, as opposed to just heat.[26] All of these explosive devices have been employed in warfare. They have also been utilized by many terrorist organizations.[35] Inevitably, Alfred Nobel created an invention that led to tools that armies have used for destruction and death for over a century. Ascanio Sobrero foretold this future and attempted to hide his discovery, but is withholding the flow of science as ethical as Sobrero made it seem?

Ethics surrounding inventions of dangerous nature is a topic bigger than Alfred Nobel. Many inventors have made hazardous and catastrophic discoveries and regretted their decisions much later in life. After contributing to the invention of the atomic bomb, the leader of the Los Alamos sector of the Manhattan Project, J Robert Oppenheimer, was quoted to have said: "Now I am become Death, the destroyer of worlds."[36] Oppenheimer led the Los Alamos project and played a large role in the overall assembly and creation of the atomic bomb. At the time, he assumed the creation of such a weapon was necessary for ending the ongoing conflict with the Axis powers. Later on, research into fission technology spiraled into the creation and testing of the H bomb. While Oppenheimer condoned research into this technology, he disapproved of its production and actualization.[37] If used, the H bomb could erase entire cities in seconds.

It should be noted that fission discoveries have also led to advancements in atomic energy, which can provide a possible solution to climate issues. Nuclear pharmaceuticals also offer a possible new frontier for new drug creation. Similar to Nobel and dynamite, both positive and negative effects resulted from this discovery. Oppenheimer and Nobel were recollective later in life, but neither considered trying to thwart their own personal research paths. Remorse surrounding the creations of inventors and entrepreneurs can come in many forms.

The most famous example of an invention of hazardous applications comes from Fritz Haber, inventor of the Haber-Bosch process in Chemistry. The Haber-Bosch process transforms Nitrogen and Hydrogen into ammonia. Ammonia is used in 99% of all nitrogen-based fertilizers and is a large reason for boosts in agriculture technology. These boosts have allowed global populations to grow and, in many areas, also caused food insecurity to shrink. Yet, the production of ammonia also directly led to the creation and use of chemical weapons.[38] Before being banned, chemical weapons were extremely dangerous and effective in warfare.[34]

Scientific discoveries, especially those with dangerous applications, raise moral questions. Should scientists be expected to suppress discoveries for the safety of the general public and to prevent devasting applications? Would this diminish the positive societal effects caused by the flow of science? If concessions need to be made, whom should we entrust to make the proper regulatory decisions?

Knowledge production relies on the publication process. Recently, the question of scientific censorship in the name of a greater good has come to light. A recent paper in PNAS has pointed out the need to better understand the consequences of scientific censorship.[39] Others over the last few years have also suggested that scientific censorship can prove detrimental to the field censored.[40] A recent paper out of Stony Brook University suggests that over the 31 institutions polled, scientific censorship is on the rise.[41]

Scientific oversight also exists in legislation. Via public oversight, inventions can be withheld from public grasp even after their inception. Regulations can be used to recall dangerous inventions from the general public, without incurring major losses. Nobel, Haber, and Oppenheimer are all examples of inventors whose inventions have been withheld from public use successfully by the government. A more childish example surrounds the children's toy *Lawn Darts*, banned in the US for safety.[42]

Science fiction writers have long imagined what would happen when technological research went awry. They describe dystopian realities created by unfettered scientific breakthroughs. Among the most popular examples are *The Terminator, The Matrix,* and the *Jurassic Park* franchises. These and other examples show that the public has become fascinated by the idea of dangerous runaway technology and research. It is clear that many of these ideas stem from a fear of the unknown, but it is also apparent that the public does not have confidence in scientists to protect them from their own research.

Yuval Noah Harari, writing about pressing issues in the modern age, provides insight into the conflicts between progress and human nature. Specifically, Harari writes, "Humans were always far better at inventing tools than using them wisely." Harari believes that humans can become blinded by their visions of good and evil and that, in the realm of scientific advancement, this can lead to disastrous implications. He also states the following: "Technology is never deterministic, and the fact that something can be done does not mean it must be done." Progress is not linear, and many assume that because something can be created, it will be created. Harari fights back against this notion, reaffirming that given the right moral reasonings, an actor like Ascanio Sobrero or a governmental entity should be allowed to disrupt the flow of research given moral qualms.[43]

In conclusion, I note that the lines drawn surrounding moral issues are often subjective. There is rarely one right answer to morality, and recently, publications have taken scientific censorship to the extreme on both sides of the political aisle. It is extremely difficult to simultaneously foresee both the costs of censorship and the repercussions from dangerous or runaway technological innovations.

We cannot let our fear of technological destruction or societal shifts due to technology bring about a dystopian future. At the same time, historical examples exist where earlier foresight could have prevented the inception of dangerous inventions. The general public may have created fearful portrayals of technological cataclysms in science fiction, but they have also envisioned oppressive regimes like in Orwell's *1984*. Both extremes must be avoided.

CONCLUSION

As discussed, a basic study of Alfred Nobel's life refutes the reported origin of The Nobel Prize as resulting from an erroneous obituary with a disturbing moniker and instead shows the impact of Nobel's interaction with pacifist Bertha von Suttner as the primary catalyst. Like other examples in the scientific discovery of dangerous technology, Nobel struggled with balancing the positive and negative effects of research and engineering. Nobel also failed to heed the warnings of preceding scientists such as Ascanio Sobrero, who had attempted to hide his discovery of nitroglycerin, a crucial component in dynamite, in Nobel's path to building an explosives empire. The conversation on this topic is ongoing and has recently gained a lot of national attention in proposed changes to school curricula and regulations surrounding scientific publication. The effects of scientific censorship require further careful study, as illustrated by this paper.

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Feature Articles

An Exercise of Applied Epistemology: Peirce's Semiosis Implemented in the Representation of Protein Molecules

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Abstract. In their disciplinary communication chemists make a broad use of iconographic means. In this paper, some aspects of the iconographic communication are discussed, with specific reference to the representation of protein molecules in the light of Peirce's and Eco's semiotics. As far as Pierce's thought is concerned, I discuss two triads (*representamen*, *interpretant*, and *object)* and (*icon*, *index*, *symbol)*. Eco's distinction between s-codes and codes is equally applied to the analysis of protein icons. The symbolic and iconic aspects of proteins' representations are discussed, in the light of various conventions that regulate the use of shapes, lines, shadows, colors in the building up of images. The iconic aspect turns out to be the most surprising, not just because it makes 'visible' what is inherently invisible, but also because of its heuristic potential. I argue that the construction of protein images and their use in research qualify their epistemic status as that of conjectures.

Keywords: semiosis, protein models, iconographic communication, Pierce, Eco

INTRODUCTION[1]

Scientific communication makes a broad use of iconographic means. Chemistry is no exception, having a long tradition of inventing and using iconographic means of expression. A renown image in the history of chemistry is the table published by John Dalton in 1808, whose caption was the following: «This plate contains the arbitrary marks or signs chosen to represent the several chemical elements or ultimate particles».[2] In fact, chemistry relies heavily on the symbolic dimension[3], that finds expression on both the linguistic level (chemical symbols, molecular formulas, chemical equations, etc.) and the iconographic level (diagrams, structure formulas, molecular models, iconic representations, etc.). The linguistic and iconographic aspects of chemical communication have been the object of a wealth of studies (see, for example, refs.[4],[5],[6],[7],[8]). Interestingly, iconography has become more and more relevant in chemistry: Weininger remarks that «the decreasing importance of linguistic signs such as names, compared to iconic signs such as structural formulas, accords with and reinforces the intensely visual character of chemistry».[9]

Over time, the use of graphical means has become increasingly widespread in chemistry, due to the need to process and make intelligible an increasing amount of structural data. Concurrently, the availability of large computing powers and the impressive development of visual softwares (diagrams, pictures, etc.) made sophisticated graphic representations available, and scientists of various disciplines developed the most different ways of representing molecular properties. The representation of the molecular realm through these tools has opened up new perspectives for chemistry researchers; at the same time, the design and use of such representations raise considerable epistemic issues[8,10,11.]

Chemical iconographical expressions are veritable working tools for chemists, as they are endowed with heuristic potential: according to Klein «Scientists often apply inscriptions or systems of signs not to present, illustrate and justify already existing knowledge, but as tools on paper for producing new representations and new knowledge».[12] Mestrallet goes even further, by stating that «molecular representations are tools for modifying reality»[13].

Weininger[9] underlines the strict relationship ("entanglement") between chemical theory, practice and representation. This view is shared by Hoffman and Lazslo who, referring to structural formulas, remark that «The writing of structures is not innocent. It is ideology-laden. It carries the modern reunification of the theoretical and the experimental».[14]

Moreover, in the educational literature, special attention has been put on the role played by molecular graphics in chemistry learning and understanding: Khanfour-Armalé and Le Maréchal remark that «the use of representations is essential for visualizing microscopic phenomena and thus helping students to solve problems»[15]. In fact, Lazlo reminds that 'to think chemically' implies the ability to absorb both textual and iconic information: «Chemists are endowed with what can be termed schizovision» [8].

Given the amplitude of the literature in this field, I have chosen to confine my analysis to the varied epistemic functions of iconic representations of proteins. In doing so, I will follow a philosophical approach that can be dubbed of 'applied epistemology'. The term is neither new nor recent. In 1989 Mark Battersby defined critical thinking as an 'applied epistemology' whose task would be to analyse the «epistemological claims that are not necessarily addressed in any discipline and deserve philosophical reflection»[16]. In 2006, Battersby wrote on *Informal Logic*: «Applied epistemology," [...] focuses the discipline towards the actual practice of how people come to and should come to justified beliefs. In an analogy with applied ethics, the study of people's actual epistemological practices can provide both information and challenges for the theoretician of reasoning»[17]. In the same year, Larry Laudan gave a good definition of 'applied epistemology': «Applied epistemology, in general, is the study of whether systems of investigation that purport to be seeking the truth are well engineered to lead to true beliefs about the world»[18]. My position towards applied epistemology is that philosophy, epistemology and semiotics have provided a wealth of sophisticated tools that can be applied to the study of theoretical and experimental scientific practices, in details. In the present exercise of applied epistemology, I mainly exploit the 'tools' developed by two authors who provided great contributions to both philosophy and semiotics: Charles Sanders Peirce and Umberto Eco.

The title of the present paper relates Peirce and semiosis; in fact, the American philosopher is counted among the founders of semiotics. Nevertheless, Peirce was more than an expert in semiotics, as he provided important contributions to the philosophy of science. These contributions are especially relevant as they come from a professional scientist, a man who knew science from inside: Peirce was a chemist by training, and from 1896 to 1902, he worked as a consulting chemical engineer for St. Lawrence River Power Co. in Massena (NY)[19]. Hence, Peirce was well-prepared to link the stringent materiality of empirical and technical facts with the abstract character of their interpretation.

ICONOGRAPHIC COMMUNICATION: SEMIOTIC TOOLS FOR AN INTERPRETATION

Peirce's intellectual production is impressive. Most of it lies in the huge amount of manuscripts conserved in Harvard (more than 100,000 pages) that cover several decades. Therefore, studying Pierce is a challenge from both the quantitative and the qualitative standpoint, because the American philosopher changed his views on important points of his philosophical system, repeatedly. In the present study, I choose to refer to the last period of Pierce's thought; quotations are excerpts from writings that date between 1893 and 1907. Similarly, as regards to Umberto Eco, I choose to mention only one of his earlier works, the treatise *A Theory of Semiotics*, published in the United States in 1976, out of the wide production of this Italian philosopher.

PEIRCE'S SEMIOTIC ANALYSIS AND SEMIOSIS

It is well known that Peirce's thought was largely based on triads. He designed several triads, with different nature and meanings. I will comment on two fundamental triads that refer to the nature and the classification of signs (Figure 1). Peirce gave many definitions of sign[20], but probably the best known (and clear) is the following:

> «A sign, or *representamen*, is something which stands to somebody for something in some respect or capacity. It addresses somebody, that is, creates in the mind of that person an equivalent sign, or perhaps a more developed sign. That sign which it creates I call the *interpretant* of the first sign. The sign stands for something, its *object*. It stands for that object, not in all respects»[21] (italics in the text).

This definition states the fundamental relation between representamen, object and interpretant (not to be confused with the interpreter). Peirce's semiotics is entirely developed from this triad, taken as a starting point. The *representamen* is intended as «something which stands to somebody for something in some respect». This is one of the main features of a sign: it has no universal character and is always addressed to somebody (not to anybody). The *interpretant* is what is created in the mind of the observer as a result of the perception/reception of the sign. The *object* cannot be fully represented by the sign («not in all respects»). Peirce seems to suggest that the expressive effectiveness of a sign is tied to both what is present and what is absent in the sign. The expressions «in some respect» and «not in all respects» draw attention towards the viewpoint from which the sign is employed. They are not logically equivalent: in fact, only the latter guarantees that other viewpoints may be taken into consideration, in addition to the one that is proposed. What is absent in the first interpretation of the sign can be (partly) found in the *process of semiosis*.

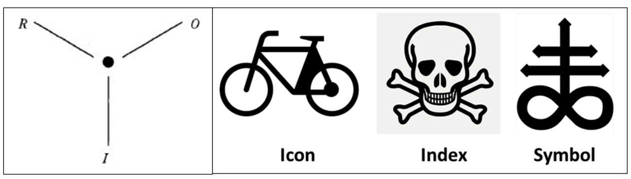

Figure 1. Left panel: nature of signs; R = representamen, O = object, I = interpretant[22]. Right panel: classification of signs. The sign associated with 'Icon' has a similarity relationship with its object. The sign associated with 'Index' is the toxicity mark, widely used by chemists to signal toxic substances. The sign associated with 'Symbol' is the Leviathan cross (sulphur in alchemy).

A sign is understood through a mental process that Peirce calls '*semiosis*':

> «An action, or influence, which is, or involves, a cooperation of three subjects, such as a sign, its object, and its interpretant, this tri-relative influence not being in any way resolvable into actions between pairs»[23].

Semiosis has to be intended as a series of mental acts. The first one – according to Peirce – is an action that involves a cooperation of three subjects, sign, object and interpretant. But the interpretant, which in turn is a sign, may become a new representamen; so, a new triad may come out and foster a further semiotic act that leads to a second interpretant, and so on. Semiosis is fostered by the fact that the interpretant is in itself «a more developed sign». Hence, semiosis is a progressive process and, in principle, an endless process. As a matter of fact, at a personal and social level, the process reaches a stable state whenever a *habit* is established. A personal habit is acquired through two interlinked processes: a recurrent experiential relationship with the sign and the correlated semiosis. Nevertheless, a personal habit is never acquired in an isolated environment. A strong interaction with other actors (i.e. a social environment) may concur to the establishment of a habit, as is the case of a research team or a teaching class. Peirce remarks that «A habit is not an affection of consciousness; it is a general law of action»[24]. A habit corresponds to the establishment of a conventional behaviour: whenever the interpretant becomes a habit, his action is no longer limited to the cognitive sphere.

Here is a simple example of semiosis: in a laboratory, a flame test is performed and the appearance of a violet color is interpreted as a (macroscopic) sign of the presence of potassium in the sample. A well-trained student correlates the presence of potassium with the occurrence of an emission process, the (microscopic) transition of an electron from a higher to a lower energy state in a potassium atom. So, the interpretant (potassium in the sample) becomes «a more developed sign», related with the excited states of potassium atoms. The process may even drift away from the scientific context and lead to the suggestion of violet as a fine color for clothes. The pragmatic aspect of semiosis is here very clear.

The effectiveness of a sign depends on the existence of a cooperation between the three elements of the triad, whose mutual relationship is dynamic. In his unpublished *A Survey of Pragmaticism,* Peirce wrote:

> «[B]y 'semiosis' I mean […] an action, or influence, which is, or involves, a coöperation of three subjects, such as a sign, its object, and its interpretant, this tri-relative influence not being in any way resolvable into actions between pairs. Σημείωσις in Greek of the Roman period, as early as Cicero's time, if I remember rightly, meant the action of almost any kind of sign; and my definition confers on anything that so acts the title of a 'sign'»[25].

Peirce stresses that the relationship is genuinely triadic and it does not result from the overlap of dual connections: «this tri-relative influence not being in any way resolvable into actions between pairs». In other words, meaning is the consequence of triadic relation of sign-object-interpretant (S-O-I) as a whole: «The triadic relation is *genuine,* that is, its three members are bound together by it in a way that does not consist in any complexus of dyadic relations».[26] It is noteworthy that the term |action| appears three times in this definition. In the same vein, Gérard Deledalle remarks that «The representamen, the object, and the interpretant stand for relations or functions»[27]. The term *relation* refers to the observer who perceives the sign; the term *function* refers to the making up of its meaning. This aspect is stressed by Floyd Merrell, who identifies the central point of Figure 1 (left panel) as a node: «a central 'node' [...] the fountain head of all sign *relata* and the locus of meaning in flux»[28]. Hence, the meaning comes out from a net of relations: «Meaning is in the interrelations, in the interaction, the interconnectedness»[29].

PEIRCE'S SIGNS

Peirce's triad reported in Figure 1 (right panel) refers to the types of sign, and it is really crucial in the history of semiotics.

It is worth reading Peirce's definitions with some comment. In a 1903 manuscript, Peirce wrote:

> «An *Icon* is a sign which refers to the Object that it denotes merely by virtue of characters of its own, and which it possesses, just the same, whether any such Object actually exists or not»[30] (italics in the text).

Two points should be emphasized. The first is that the icon refers to the object through the specific, graphical, visible and proper characters of the icon itself. Peirce often speaks of diagrams as typical examples of icons. The second point is that an icon may refer to a non-existing object: this means that the icon opens towards possible worlds. This highlights the 'arbitrary' and creative nature of the making of an icon, as we will argue further on, while discussing Eco's s-codes.

The image of the bycicle reported in Figure 1 is an Icon in that it has a similarity relationship with its object ("a sign by Firstness"[31]). Concerning the index, Peirce wrote:

> «An *Index* is a sign which refers to the Object that it denotes by virtue of being really affected by that Object. In so far as the Index is affected by the Object, it necessarily has some Quality in common with the Object and it is in respect to these that it refers to the Object»[32] (italics in the text)

In the laboratory, chemists create experimental situations in which precipitates of various colours and behaviours are produced, so that a chemist may deduce, for instance, the presence of Ag^{+} or Pb^{2+} ions in solution. In these cases, perceptible colours and behaviours are indexes that refer to specific microscopic events and particles. The image of the skull reported in Figure 1 is an Index in that chemists use it as a mark of toxicity for poisonous substances.

The last fundamental kind of sign is the following:

> «A *Symbol* is a sign which refers to the Object that it denotes by virtue of a law, usually an association of general ideas, which operates to cause the Symbol to be interpreted as referring to that Object»[33] (italics in the text)

The term 'law' remarks the conventional, inter-subjective, cultural nature of symbols. Namely, the number 9 and the term Country are symbols by virtue of very different conventions; nonetheless, both are very structured, and induce a specific behaviour. The Leviathan cross reported in Figure 1 is a Symbol as it used to stand for the element Sulphur in alchemy.

The three categories proposed by Peirce do not define disjoint sets of signs, otherwise many images found in scientific texts could not be interpreted according to Peirce's semiotics. It is evident that an image such as Figure 2 cannot be catalogued under just one out of the three fundamental categories of signs. Peirce was well aware of the question, and stated:

> «One sign frequently involves all three modes of representation; and if the iconic element is altogether predominant in a sign, it will answer most purposes to call it an icon»[34]

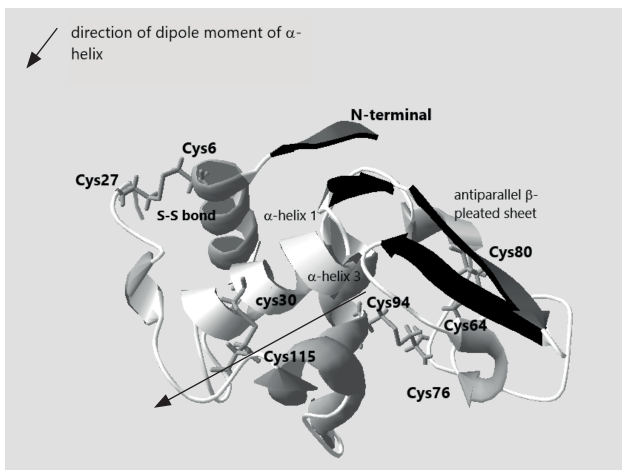

Figure 2. Representation of the 3D structure secondary and tertiary interactions of the enzyme lysozyme (PDB entry: 2VB1; image generated by Swiss PDB Viewer 4.1.0)

Figure 2 is just an example of the use of mixed signs. The different types of arrow mean distinct properties: the direction of the helix dipolar moment, the direction of beta-strands, etc. All of them have distinct implications in terms of interpretation of the behaviour of the object. The symbolic character is made evident by the presence of letters or writings that describe the nature of specific sites within the protein. The indexical character is evident in the arrows that are related with the dipole moment of helix, that is actually found in the object. Finally, the iconic character is given by the ensemble of this representation of a protein.

The two triads that we have analysed display a very different character. The first triad (representamen, interpretant, object) has a philosophical nature: it defines the sign and helps interpreting its function. Therefore, it is the basis for semiosis.

The second triad (icon, index, symbol) has systematic purposes: it helps classifying signs. Like any classification, it may be further detailed, depending on the features that need to be highlighted. Peirce himself proposed further classifications of signs and triadic diagrams: a first division in 10 classes (exposed in the Syllabus diagram, 1903) that subsequently engendered a system of 66 classes (Welby diagram)[35]. According to Romanini: «The 66 classes of signs arranged in […] triangular shape show regular periods revealing the increase of complexity of semiosis as it reaches communication, as well as phases that describe the whole process of inquiry»[36]. In our context, we refer just to the first level of such classification.

Semiosis can be understood as the dynamic process of producing subsequent interpretations by the observer. The signs as such also possess an 'extrinsic' dynamics:

> «Symbols grow. They come into being by development out of other signs, particularly from icons or from mixed signs partaking of the nature of icons and symbols. We think only in signs. These mental signs are of mixed nature; the symbol-parts of them are called concepts. So it is only out of symbols that a new symbol can grow"»[37]

In addition, signs are not fixed: they evolve with time. The causes of such evolution are varied. Figure 3 shows two renown models, that marked key-steps in protein crystallography. The model in Figure 3 (left panel) was built when the group led by John Kendrew obtained data of myoglobin's structure at 6 Å-resolution. At the time, Kendrew's problem was to get myoglobin's structure at atomic resolution; in 1960 he was finally able to build up the model reported in Figure 3 (right panel), where each single atom of myoglobin (apart hydrogen atoms) has its 'place' in the 3D space.

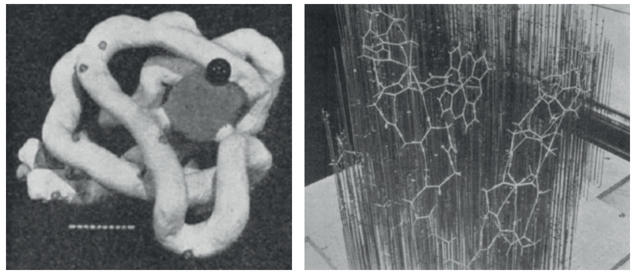

Figure 3. Kendrew's models of myoglobin's structure. Left panel: the model was made up with plasticine in 1957, at 6 Å-resolution. Right panel: the model of myoglobin at 2 Å-resolution, dubbed 'forest of rods', was built in 1960[38],[39] (Reprinted by permission from Macmillan Publishers Ltd).

The models in Figure 3 are typical of cognitive situations in which the scientist is faced to different sets of data and builds up a sequence of models whose 'completeness' depends on the quantity and quality of data that the model aims to interpret. The two pictures in Figure 3 emphasize the 'materiality' of Kendrew's models, a materiality that does not prevent models from being perceived as signs. In a 1908 manuscript, Peirce refers to the monuments that are found in North American towns and villages, which portray a Union soldier of the Secession War. Peirce states: «That statue is one piece of granite, […] yet it is what we call a 'General' sign»[40]. A similar position on the iconic character of material objects was expressed in 1938 by Charles Morris in an important contribution to the theory of signs: «A photograph, a star chart, a model, a chemical diagram are icons, while the word 'photograph', the names of the stars and of chemical elements are symbols»[41]. Even though the information to be represented is the same, the mode of representation may be different and is subjected to evolution.

Figure 4 still refers to myoglobin and reports its 3D structure as a 'ribbon diagram' (or 'Richardson diagram'). Aim of this kind of model is to highlight structural features (secondary structures, the position of prosthetic group, etc.) that may help understanding the protein function.

In spite of referring to a same object (myoglobin), Figure 3 and 4 convey distinct messages and originates from different purposes.

S-CODES VS. CODES: ECO'S LESSON ON SIGNS

It is now worth recalling a classification proposed by semiologist Umberto Eco in 1976. It refers to the distinction between 's-codes' and 'codes', that turns out to find a direct validation in the images that we are analysing.

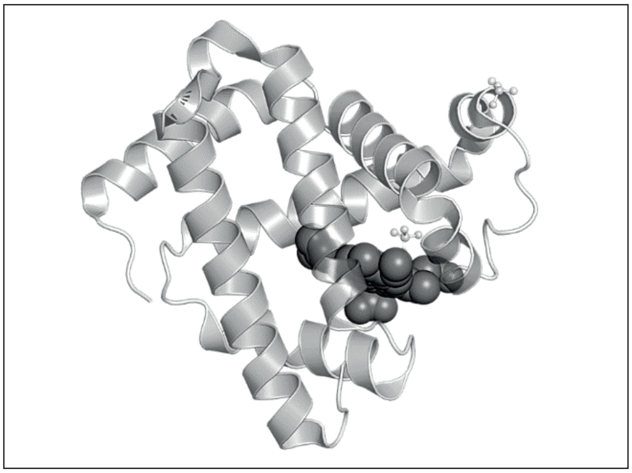

Figure 4. The 3D structure of myoglobin represented as a 'ribbon diagram' (PDB entry 2OH8; image generated by Swiss PDB Viewer 4.1.0)

Eco defines three types of s-codes (where the 's' stays for system): syntactic, semantic and behavioural. He also differentiates them from codes. In his own words:

a. A syntactic system is «A set of *signals* [signs] ruled by internal combinatory laws»; «they could convey different notions about things and they could elicit a different set of responses»[42] (italics in the text).
b. A semantic system is «A set of *notions* [...] which can become [...] a set of possible communicative contents»; «they could be conveyed by any [...] type of signal, such as flags, smoke, words, whistles, drums and so on»[43] (italics in the text).
c. A behavioural system is «A set of possible *behavioural responses* on the part of the destination»; «these responses are independent of the (b) system». «They can also be elicited by another (a) system»[27] (italics in the text).
d. A code: «A *rule* coupling some items from the (a) system with some from the (b) or the (c) system». «This rule establishes [...] that both the syntactic and the semantic units, once coupled, may correspond to a given response». «Only this complex form of rule may properly be called a '*code*' »[27] (italics in the text).

Systems (a), (b) and (c) share the property of being completely arbitrary and independent from each other. These features are relevant to the communication process because they leave the greatest possible freedom to those who have the task or the intention to communicate. A code assures a great freedom of choice over systems (a), (b) and (c), too.

Eco points out that the confusion between codes and s-codes can lead to «considerable theoretical damage». Thus, he introduces a sharp terminological distinction:

> «I shall therefore call a system of elements such as the syntactic, semantic and behavioral ones outlined in (a), (b) and (c) an *s-code* (or code as system); whereas a rule coupling the items of one s-code with the items of another or several others-codes, as outlined in (d), will simply be called a *code*»[44] (italics in the text).

In a nutshell, s-codes may be understood as |sets| and codes as |functions| that connect different sets. Or, with a less restricted definition, one can speak of s-codes as |rules of the game| and speak of codes as |game's styles|.

An example of the application of semantic, syntactic and behavioral s-codes and codes to the representation of protein structures may be found in Figure 5. The use of different colors or color shades, as well as continuous or dotted lines, pertain to the syntactic aspects that define the 'pictorial alphabet' on which the representation is based. The semantic s-codes disclose the interpretation-keys of the figure: e.g. dashed lines are H-bonds, black lines stay for aminoacids interacting with the heme group, etc. The behavioural s-code follows closely, as it defines how the picture must be read. It influences the reader's reaction in that the observer may formulate working hypothesis based on this picture and plan experiments aimed at verifying them. Another example of interpretation of chemical contents in terms of codes and s-codes is offered by chemical equations that chemists use to describe chemical transformations. In that case, the syntactic s-code is represented by the use of different symbols and combinations of symbols and numbers, to give chemical formulas and their combination (according to Jacob, «It is possible to distinguish between a chemical orthography and a chemical grammar»[7]). The semantic s-code lies in the interpretation rules of such formulas. The behavioural s-code allows reading that combinations of alpha-numerical signs in term of specific substances reacting on a molar bases. Coupling these s-codes result in the possibility, for the reader, to foresee the outcome of a chemical process carried out in specific conditions, or to design another process based on the premises posed by this one. This goes along with Wightman's analysis of chemical formulas, as he maintains that combining letters (chemical symbols) with numbers «changed the status of 'symbols' in the restricted sense from mere abbreviations […] into the elements of an 'algebra' and later a 'geometry' or 'topology'».[5] Other examples could be proposed: resorting on

Eco's codes and s-codes is useful in that it allows highlighting the multifaceted character of the symbolic language through which chemistry describes its mental and practical operations.

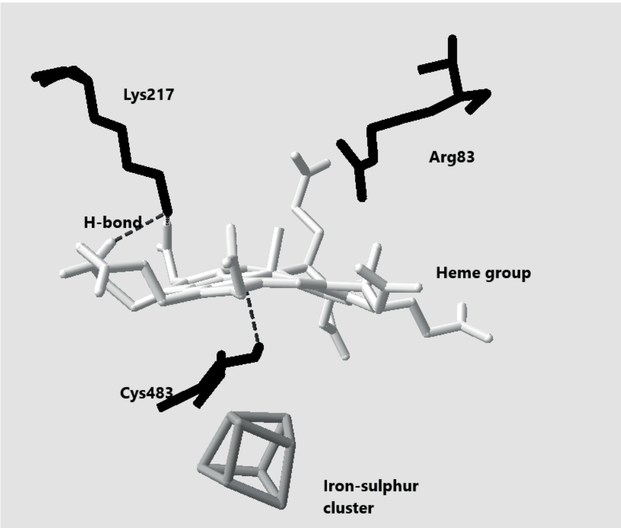

Figure 5. Representation of the active site of enzyme sulfite reductase (PDB entry 1AOP; image generated by Swiss PDB Viewer 4.1.0)

In the perspective of Peirce's thought, protein icons and their related codes and s-codes foster abduction processes, as they play a role in the process of construction of scientific knowledge. The concept of abduction is probably the most important contribution given by Peirce to the philosophy of science. The distinction between abduction and induction or deduction is clearly explained:

> «Abduction is the process of forming an explanatory hypothesis. It is the only logical operation which introduces any new idea; for induction does nothing but determine a value, and deduction merely evolves the necessary consequences of a pure hypothesis»[45]

The relationship between abduction and icon is also well expressed by Peirce:

> «An [...] Abduction, is an argument which presents facts in its Premiss which present a similarity to the fact stated in the Conclusion, [...] so that we are not led to assert the Conclusion positively but are only inclined toward admitting it as representing a fact of which the facts of the Premiss constitute an Icon»[46]

More concisely, a 1903 manuscript reports: «Abduction, or the suggestion of an explanatory theory, is inference through an Icon»[47]. Scientific research practices confirm the rightness of Peirce's thought, because the inspection of protein icons fosters the formulation of hypothesis that could not be disclosed by the mere examination of big sets of numerical data.

THE REPRESENTATION OF PROTEIN MOLECULES

An astonishing aspect of protein icons is their ability to represent what is not representable: they are an attempt to visualize microscopic objects and chemical-physical properties. One could say that these pictures *make abstractions visible*. Let's take the example of potential surfaces: they do not materially exist and are the transposition, in pictorial terms, of sets of numbers related with a physical property. Should these numbers be arranged in a table, the reader would not be able to place them within a horizon of meaning. The switch to iconic representations allows providing numbers with an operational meaning, that fosters the formulation of further hypothesis and the planning of investigations. The switch from numbers to icons conceals the use of analogy as interpreting tool: iconic language allows representing channels, grooves, surfaces, shapes, etc... These terms, borrowed from natural language, clearly refer to the macroscopic realm and, taken as such, could not apply to the microscopic world. Nevertheless, resorting to analogies discloses the impressive heuristic potential of icons. In fact, based on these images the reader may formulate hypothesis about the possibility of hosting a molecule inside a 'protein pocket' or to make substrate-protein contacts mediated by a specific charge distribution on the 'protein surface'. In other words, analogies inherent to iconic representations of properties and features of the microscopic world allow handling an otherwise inaccessible realm and interpreting its behavior.

The application of s-codes to the making of a pictorial representation responds to both inter-personal communication and interpretation purposes. The inter-personal communication is achieved when distinct people in distinct places read the picture in a same way. This implies the definition of conventional s-codes, that are employed in the making of the figure and are approved by a disciplinary community. Interpretation purposes are directly related with behavioral s-codes: the icon makes evident what numbers would conceal, e.g. the possibility to accommodate a substrate within a pocket, to track an internal electron-transfer pathway, to make adducts with other molecules, etc.

The analysis of signs according to Eco's s-codes emphasizes the conventional character of signs, and therefore, according to Peirce, their symbolic aspect. A relevant feature of symbols is that their meaning is multifarious. Peirce remarks that:

> «The entire intellectual purport of any symbol consists in the total of all general modes of rational conduct which, conditionally upon all the possible different circumstances and desires, would ensue upon the acceptance of the symbol»[48]

A similar viewpoint is echoed by a passage of Roland Barthes's writings:

> «It follows that the meaning of a text lies not in this or that interpretation but in the diagrammatic totality of its readings, in their plural system», «The meaning of a text can be nothing but the plurality of its systems, its infinite (circular) 'transcribability'»[49]

The reference to 'the total of all general modes of rational conduct' in Peirce's excerpt, just as Barthes' «diagrammatic totality of its readings», underlines that a symbol has a multiplicity of interpretations that are in dialogic relationship between each other. In the language of semiotics, one can say that there are multiple codes and s-code for each symbol. Such multiplicity discloses different aspects of the symbol's object. Hence, «Different systems of expression are often of the greatest advantage»[50], but the actual nature of the object to which the symbol refers remains somehow unattainable.

The set of iconic representations in Figure 6 are a good exemplification of Peirce's and Barthes's statements: all these images refer to a same object, a same protein molecule. Each of them provides a different view of the system, depending on the properties that the designer wishes to highlight. Some of them provide structural hints, by highlighting secondary and tertiary structures; some others suggest functional or relational behaviors, by highlighting regions of distinct charge density or the presence of acid or basic sites. Interestingly, the less useful representation is the one that contains the higher amount of the structural information (panel A), as it reports the position of all atoms in the structure and implies no data selection. The comparison between distinct representations shows quite clearly that data selection is essential to the assignment of meaning. Namely, secondary structures become evident only by discarding information about lateral chains of aminoacids; otherwise, any possibility of spotting features like crucial interactions within the structure or stable domains, is missed.

Figure 6 is also representative of distinct syntactic and semantic s-codes applied to a same microscopic object. Here it becomes clear that s-codes are the base for representation, whereas codes are the base for interpretation and depend strictly on the purpose of the modeler. So, this figure discloses very clearly the role of the modeler's intentionality: depending on the modeler's aim, a different set of s-code is used and a different code is generated. Depending on one's interest in structural stability aspects or in understanding the way a protein may interact with another protein, one may choose to represent the system in distinct ways.

The peculiar epistemic value of icons is well expressed by this excerpt of Peirce's writings:

> «[A] great distinguishing property of the icon is that by the direct observation of it other truths concerning its object can be discovered than those which suffice to determine its construction. [A] capacity of revealing unexpected truth»[51]

This is strongly related with the previously mentioned heuristic potential of icons. According to Peirce, the mere observation of an icon has the power of disclosing truths about the object, truths that escaped even to the icon's maker. This statement is amazing in several ways. As we have seen, Peirce clearly assigns to icons an important role in abduction processes: they are tools in the construction of (scientific) knowledge. We already remarked that the inspection of an icon representing a protein model allows disclosing the presence of binding sites and regions of structural stiffness or plasticity, the ability to establish specific interactions with other molecules through superficial contacts, etc…Interestingly, these aspects are all enclosed in the set of numerical data that are needed for building up the pictures. But the heuristic value belongs to the pictorial representation and not to the raw sets of data: it does not belong to numbers, it belongs to the iconic representations of subset of numbers, chosen by the modeler's intention. Numbers have clearly no inherent meaning: they need a hermeneutic action, capable of putting them inside a specific frame that provides them with a meaning. The cognitive potential does not lie in numbers; it rather belongs to their various representations that, in turn, are the result of specific choices of the icon's designer.[52]

This leads to discussing Peirce's view on the process of building up of scientific knowledge. Pierce's analytical mind established a classification of epistemic shades, based on the subtle distinction between presumption, guess, conjecture, surmise: «An increase of information by induction, hypothesis, or analogy, is a

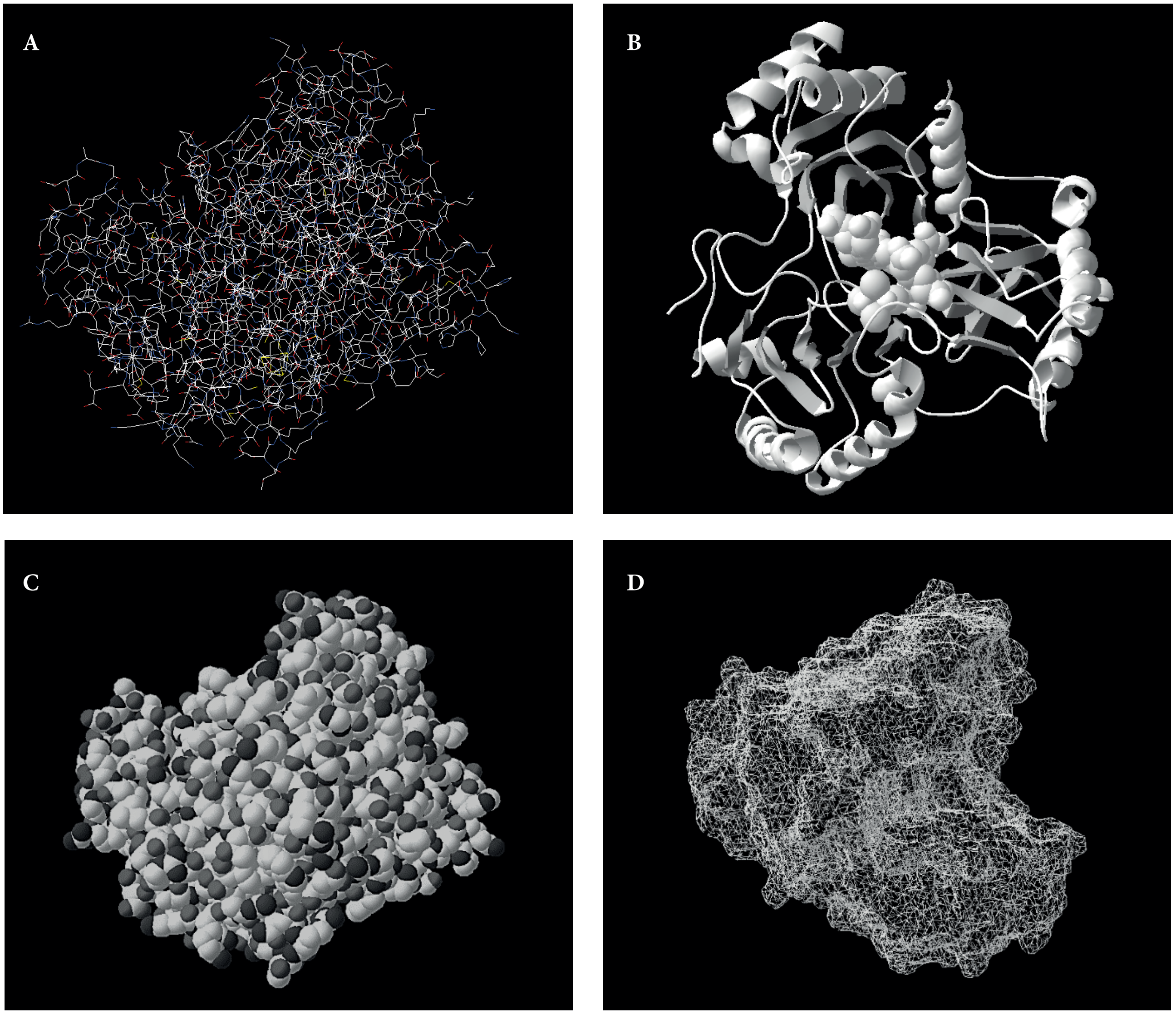

Figure 6. Representations of the 3D structure of enzyme Sulfite reductase: A) CPK representation; B) ribbons representation; C) Van der Waals radii representation; d) protein surface representation (PDB entry 1AOP; image generated by Swiss PDB Viewer 4.1.0)

presumption. [...] A very weak presumption is a *guess*. A presumption opposed to direct testimony is a *conjecture*, or, if weak, a *surmise*»[53]. Based on his own words, scientific knowledge aims at ascertaining the truth, but this truth is not the mere result of strictly logical operations. A good deal of creativity lies in what Pierce calls abduction:

> «it must be admitted that the only method of ascertaining the truth is to repeat this trio of operations: conjecture *[the abductive hypothesis];* deductions of predictions from the conjecture; testing the predictions by experimentation (not necessarily what is technically so called, but essentially the same thing -- trial)»[54]

Two important aspects of Peirce's thought emerge from this two excerpts from Peirce's writings: i) the definition of conjecture, intended as a presumption that does not rely on direct testimony; ii) the role of conjectures in the abduction process.

According to Peirce's thought, any microscopic object, an atom, a molecule, a subatomic particle, that cannot be the object of direct testimony is a conjecture. So, the basic conceptual tools of chemistry, taken as a science that explains macroscopic phenomena through the conceptualization of a microscopic level, are conjectures. This is true for proteins' structural models as well. Conjectures are put at the centre of the abduction process. In the construction of scientific knowledge, abduction comes first: it foregoes deduction or induction, which are way of relating a hypothesis with an experimental evidence. Instead, abduction deals with the way hypothesis takes shape. Peirce closely links the epistemological process of abduction to the physical one of visual perception: «abductive inference shades into perceptual judgment without any sharp line of demarcation between them»[55]. He remarks that «Abduction furnishes all our ideas concerning real things, beyond what are given in perception, but is mere conjecture, without probative force»[56]. This implies that researchers represent molecular systems projecting shapes and entities belonging to their own macroscopic ontological level (balls, ribbons, channels, pockets, etc.) to the atomic-molecular level.

The main consequence of this shift in focus is to emphasize that the basis of scientific knowledge is not pure rationality, but rather creativity. Investigators of a given system or phenomenon need *to imagine* relationships and behaviors, whose plausibility will subsequently be proved or disproved through properly built experiments. This resorting to something that does not belong exclusively to the rational sphere is found in both experimental and theoretical practices: «The role of the imaginary and the fictional in chemistry […] exceeds that found in any other science».[9]

Based on the premises of Peirce's thought about conjectures and Eco's thought about s-codes and codes, I believe that proteins' icons can be taken as conjectures in a double sense:

i. they are conjectures on the representability of the microscopic realm, that is not accessible to direct testimony. They are attempts to make visible the invisible (or the abstract). In proteins' icons, we find visual representation of a number of physical properties and features that have a purely abstract character and can be expressed by numbers.
ii. they are conjectures in a more strictly epistemic sense, in that they are tools of the abductive process. Thanks to iconic representations, one can formulate hypothesis on the stability, function, behaviour and/or mechanism of the microscopic object that is represented.

Two further aspects of conjectures that may be related with Eco's thought on codes and s-codes are formulations and effectiveness. Formulation of a conjecture implies the use of a set of s-codes, that define 'the rule of the game'. S-codes are tools, whereas the code employed in handling the conjecture is the final aim. It is the code that leads to the formulation of hypothesis.

In summary, I tried to use some elements of the semiotic theory by Peirce and Eco's theory of codes as tools for carrying out an epistemic analysis of visual representations of proteins and the way these icons are employed by researchers.

My conclusion is that protein icons, and more generally, icons referring to microscopic objects that are part of the chemical explanation of phenomena, are conjectures (in Peirce's acceptation).

Other relevant aspects of the use of icons of the molecular world are the following: i) the assignment of meaning requires selection of data: big dataset do not possess an inherent meaning; ii) iconic representations make visible what cannot be visualized, either because microscopic or abstract. In doing so, they contribute to the construction of reality: "If we think of chemical signs as nothing more than 'fingers' pointing to a predetermined reality, we slight their unique and invaluable creative functions"[9]; iii) icons possess a heuristic potential, that make them instruments of the abduction process. As regards this latter aspect, I'd like quoting the motivation provided by the Royal Swedish Academy of Sciences to the assignment of the 2017 Nobel prize for Chemistry to the reserchers who developed cryo-electron microscopy: «A picture is a key to understanding. Scientific breakthroughs often build upon the successful visualisation of objects invisible to the human eye»[57]. It is doubtless that the impressive advances in the understanding of the behaviour and structure-function relationships of biomolecules occurred in the last decades owe something to iconic representations.

In conclusion, I believe this reflection on the role of iconic representations in scientific investigations, in the light of Peirce's and Eco's thought, provide some hints on the mental processes that chemists operate when they propose explanations at the microscopic level for phenomena observed in the macroscopic realm.

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Feature Articles

Teaching Chess History to Students in Natural Sciences: How to Do It and Why

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Abstract. Lying halfway between science and art, chess presents an excellent model for instructing the new generation of scientists about the merits of artistic senses for the exhibitions of scientific creativity. With this goal in mind, a course for intermediate to advanced chess enthusiasts and aspiring scientists was designed and taught in a condensed form to a group of K-12 students as a prototype for a course that could be included to higher education curricula in the near future. As per the course design, each of the twenty weekly lectures in the semester elaborates a single chess game in a chronological order of their play, starting with the mid-19th century games played in a romantic style and ending with the recent computer engine games, where the romanticism of chess playing styles is being rediscovered, thus closing the circle of dominant chess playstyles throughout the history. This closed circle is interpreted in the context of the author's lifelong effort to romanticize modern science. According to this effort, science, which has garnered over time increasingly unromantic traits and is associated today with managerial entrepreneurship, exploitative capitalism, cutthroat competition and fake elitism more than with quixotic ideals of arts, beauty and poetry, must be actively infused with lyricism and inspirational ideas and challenged for its retrograde reductionism. Each game in the course is explained in the context of the cultural zeitgeist of the decade in which it was played and also tied with famous experiments or general trends in natural sciences of the time. As the class proceeds along the 180-year long timeline encompassed by the course, it becomes increasingly obvious that developments in chess have closely reflected the trends in arts and natural sciences of the corresponding times, which is a parallel that is being drawn in this paper for the first time in the history of this board game. Because the major trends in chess and in natural sciences appear to have mirrored each other throughout the history, familiarizing oneself with the chess history up to the present times can be used as a means of evidencing the nascent and predicting the upcoming trends in sciences, and *vice versa*. Correspondingly, one major objective of the course has been to accustom students to recognize in chess games analogies for phenomena in distant domains, including those where their creativity in scientific research is being exhibited. The satisfaction of the students expressed in surveys distributed at the end of the condensed course attested to their finding in it a useful stop in their quest for the sources of inspiration for the further tracks of their scientific careers.

Keywords: Chemistry; Chess; Creativity; History; Pedagogy; Physics.

INTRODUCTION

The semantic power of the analogy is primordial, practically as old as the human thought. Narrative arts, for one, resonate strongly with humans because of providing analogies with their lives. Scientific discoveries also frequently owe to analogies with phenomena from distant domains of experience. Although chess is not commonly interpreted as a narrative, the course of a chess game or its hidden variations can be perceived as a plot, meaning that chess games can relate to our intellects in the same way as stories do[1]. This ability of chess to serve as an analogy for our lives lies embedded in the storylines of numerous books and movies. In Ingmar Bergman's *The Seventh Seal*, for example, a medieval knight is being summoned by Death to play a game of chess that would determine the course of his life[2]. Likewise, in *Blade Runner*, the replicants are all chess masters who communicate with their creator through games of correspondence chess[3].

The systematic lack of creative thought capable of conceiving conceptually novel ideas haunts today's scientific community like a plague. Today's young scholars and seasoned scientists are solidly trained to design technical novelties, but not so much the conceptual. Compared to the technical novelties, which are usually based on implementing greater processing speeds or introducing more robust devices to experimentation, conceptual novelties are more subtle but also more groundbreaking, bringing about fundamental changes to methods, models and modes of performance in science. These changes need not be as profound and substantial as those introduced by the frameworks of, say, theory of relativity or quantum mechanics, notwithstanding that the seminal findings of these two theories illustrate well what is meant by the conceptual innovation in science. Conceptual novelties, in fact, can be more modest and take the form of, for example, reversal of the cores and shells of typical composite nanoparticle compositions used in tissue engineering and drug delivery[4], or the reversal of the mainstream idea of controlling the differentiation of stem cells into various phenotypes by focusing instead on the conversion of differentiated primary cells to a pluripotent phenotype[5]. Conceiving of a nanoparticle modeled after an astral body[6,7]; creating models for predicting cell fate based on the indigenous arts of African storytelling[8] and Micronesian canoe voyaging[9]; proposing alternative biological models for assessment of material properties[10,11] and models for assessing the journey of a nanoparticle through the body[12] also count among such modest conceptual innovations in the materials science world. Another example can be that of lipid bilayer vesicles, aka liposomes, as drug delivery carriers – proposing them for this role counts as a remarkable conceptual innovation, but altering their composition and structure or studying the many ways of achieving synergies in therapeutic safety or efficacy via different vesicle/drug combinations does not, except for very special conditions. As yet another example, the prediction, the discovery or the explanation of a physical phenomenon such as superconductivity may count amongst conceptual innovations, but the dreary search for materials with a lower and lower critical temperature by adding up chemical elements in different orders and amounts would not.

Sadly, however, today's scientific climate is such that scientists are much more prone to come up with incremental ideas that are mere derivatives of concepts already in place than to conceive of experiments that could change the outlook of whole fields of science for good. To distill a cure for this pervasive dearth of creative thought, it pays off to reach with our interests outside of the writer's blocks, that is, boxes, and acquaint analogies applicable readily to the scientific problems of interest. The hypothesis that chess can serve as one such source of analogies that boost creativity, which may currently be at an all-time low in natural sciences, pervades this paper and the idea behind the course on chess and natural sciences that it describes. In fact, numerous studies demonstrating how the exposure to chess instruction at various educational levels improves learning in different domains, ranging from math[13,14,15] to reading[16] to poetry interpretation[17] to general learning capacity[18,19], are a strong indicator that analogies such as those explored here can prove useful for replenishing the dried wells of creativity amongst both the new and the old generations of scientists.

The academic course elaborating these analogies was designed in the form of one-credit hour weekly sessions, each discussing in-class a single game of interest from the history of chess. The twenty games to be discussed over the twenty weeks of a single semester follow a chronological order and form a closed circle, starting, symbolically, with the romanticism of chess in the 19th century and ending with the romanticism rediscovered by the contemporary chess engines. The importance of providing this historical perspective on the evolution of chess playstyles can hardly be overestimated. The reason is that familiarity with the history of any art or communicational medium in general encourages scientists to put their own science in a historical perspective, which presents the first step in coming up with conceptual novelties. Such novelties are inextricably tied to the historical line of progress and the turnover of trends in a given discipline.

Most academic courses on chess have revolved around the building of fluency in the game under the assumption that this would positively affect learning in other academic subjects, primarily those integrating mathematics, logics and analytical reasoning. However, there are ways to go beyond simply teaching the rules and the principles of chess and expecting that students would spontaneously form neural connections that foster the learning process in other disciplines, notwithstanding that even through the exposure to one such relatively rudimentary coursework, a lot can be achieved, including the enhancement of analytical intelligence, the building of a general learning capacity, proliferation of intercultural bonds, promotion of the inclusion of underrepresented and underprivileged social groups, and the fosterage of integration of high technologies, all of which count among the advanced priorities of bringing chess to educational settings[20]. Among the many possible syllabi that would cover these more advanced grounds where chess, art and science intersect, no academic course, to this author's knowledge, has yet attempted to correlate through analogies chess games with scientific phenomena or with principles governing the experimentation or theorization pertaining to these phenomena. The course described here, therefore, strays from the beaten path and explores pedagogic grounds not probed before.

Each game selected for this course was the result of long and exhaustive analyses and over thirty years of personal experience in the theory and history of chess. Each of these twenty games is discussed with the students in its entirety, from the first to the last move, so as to build chess fluency alongside exploring its subtler strategic and tactical features. Given the topic of the course, most attention, naturally, is being paid to particularly relevant moments and positions in each game, from which valuable analogies applicable to natural sciences could be derived. Moreover, because chess is a game that inspires, the elaboration of the analogies between the arts of chess and science tried to be as inspirational as possible, with the understanding that this inspiration is the key to boosting the students' creativity in natural sciences. To elicit this inspirational potential, chess is being treated in the course as a form of art rather than a sport, let alone recreational mental gymnastics, and the competitive aspect of the game is being steadily deemphasized, while the aesthetic aspect is accentuated.

Portable game notations (PGNs) of all the games for which no such information is included in the corresponding figure captions are retrievable from *www.chessgames.com*. The list of games discussed in the course of the semester includes private, uncompetitive games played by the author 30 or more years ago, either against human opponents or engines, so as to encourage the students that even purely amateurish games and those played in training against an engine can be researched for analogies that could mean millions, for their lives and their sciences alike. For the sake of promotion of inclusivity and diversity, a portion of the games chosen for the discussion were played by female chess players and also by children, either at various official competitions or in casual settings. For such private games discussed in this paper, PGNs are given in the relevant figure captions. A whole lot of discussion about the games anticipated to occur in a real-life instructional setting is not captured in the paper because of the space limitation, meaning that the readers as well as potential students should still find the attendance of the class a valuable learning experience. This is additionally so because the in-class discussion should always follow a partially improvisational style and be open to changing the flow impromptu depending on the interests and points brought up by the class. Hence, even a complete explication of discussion from a single exemplary course captured here need not discourage future students from attending it.

WEEK 1, YEAR 1844: HOFFMANN VS. PETROV

For hundreds of years preceding the late 19th century, the game of chess at its highest level was played in a romantic fashion. As per this style, sacrifices of minor and major pieces were made casually in the effort to heroically and resolutely attack the opponent's king, which would often take valiant strolls up and down the board, fearlessly facing the attack. Meanwhile, gambits were favorite openings of the romanticists and pawns were regularly being given away, either to distract the opponent or to open files and diagonals so as to facilitate the attack. The simplistic premise underlying this style was that the side having the initiative is the only one that could emerge as a winner. In turn, any defensive tendencies were looked down upon, not only as ineffective, but also as unpleasing for the eye, as nearly all victories, especially the most prized of them, were owing to a sharp middlegame attack. Occasionally, the chess theory did venture into analytical territories showing that the pawn structures and formations were important, as in studies by the French composer, André Danican Philidor, and that the correct defensive play could neutralize almost any attack, as in analyses by the German player, Louis Paulsen. However, the world's best players for most of the 19th century, including the likes of La Bourdonnais, Adolf Anderssen and Paul Morphy, could be classified as pure romanticists. Although basic positional principles started to emerge sporadically by the mid-19^{th} century, they never got rooted in the dominant chess culture until later in the century, when Wilhelm Steinitz became inaugurated as the first world chess champion. Beethoven, famously, started off as a classicist, but then drifted into romanticism, the movement in music he singlehandedly defined, while Steinitz, conversely, was a romanticist who gradually adopted the positional playstyle. The direct correlation between the adoption of this new style – which anti-Semite Aryans, who gravitated toward romanticism, classified at the time, casually albeit scandalously for today's standards, as dull and "stingy"[21] – and Steinitz's success at winning and then retaining the world champion title helped it establish itself as the dominant approach to chess by the time the new century rolled around. Today we know from the history of very productive but also very inhumane political systems that concluding about the benevolence or progressiveness of such systems solely based on their production capacity and wealth that they generate is as wrong as the deduction of trueness of logical premises because of the congruency of their inferences with empirical observations, which William James and pragmatic philosophers of science demonstrated early on in the 20^{th} century. However, in the late 19^{th} century, one such observation would hardly be supportable by facts and, as a result, romanticism began its slow decline in the hands of rationalists and departure from the chess world. Nevertheless, transitions between developmental stages, in any existential domain, are such that the features of a new stage initially mix with and gradually take over the traits of an old stage[22], and a similar effect occurred in chess, which had to wait for the times of Capablanca in 1910s to encounter for the first time a style completely devoid of any romantic predispositions and propensities.

The trends in art mirrored closely those in chess, or *vice versa*. The romantic movement in arts emerged in the late 18^{th} and the early 19^{th} century from the backlash of poets and spiritualists against the rising rationalism and the dryness of the intellect that had become pervasive during the age of enlightenment and in the wake of the industrial revolution, and this turn of tides was reflected very well in the chess playing style adopted by the leading players of this period. Moreover, only when chess started shedding the skin of romantic aspirations did arts start doing the same too. Romanticism in visual arts and music peaked in the first half of the 19^{th} century and simultaneously with the shift in the dominant chess playing style to the more prosaic positional grounds from the middle of the 19^{th} century onwards, mainstream art started shifting toward realism, which is typically tied to the period between 1840 and 1870, and then toward less long-lived movements, such as naturalism, symbolism, impressionism and others. In science, too, the approach existent since the times of renaissance and all the way to the second half of the 19^{th} century was such that the most prolific scientists were either art aficionados or aspiring artists. Even during the age of enlightenment, when the emphasis on emotionless empiricism and rationality began to suppress the free expression of emotionality and the transcendent aesthetic experience[23], which romanticists would later try to revive, scientists were far more polymathic than they are today and were nurturing a variety of interests. These interests commonly transcended their sciences, which were freely cross-fertilized with impressions from art and philosophy. In other words, there were times, not so long ago, when science and art coexisted and complemented each other in a more holistic approach to studying the wonders of the physical world than it is the case today, when science is wholly divorced from arts. Scientific texts were, as a result, often pervaded with aesthetic observations and one example comes from the seminal works of Michael Faraday on the segregation of grains of sand on sonorously vibrated beds[24] and on the production of the first gold nanoparticle colloids[25] from 1831 and 1857, respectively, the former of which mentions the words "beauty", "beautiful" or "beautifully" whole 35 times in its course and the latter of which opens with a 153-word long sentence starting with a blatantly poetic exclamation: "That wonderful production of the human mind, the undulatory theory of light…". Given that chess is arguably more proximal to art than natural sciences are, the papers and books on chess analytics from the same, mid-19^{th} century period were suffused with poetic wordings to an even greater degree. The writings of Howard Staunton, for one, who is nowadays remembered as the pioneer of the scientific approach to the game, abound with such statements, as when he calls gambits "the most brilliant and animated of all the openings, full of hair-breadth 'scapes and perilous vicissitudes, but affording an infinitude of beautiful and daring combinations", or when he christens the knight "at once the most striking and most beautiful of all the Pieces; the singularity of its evolutions, by which it is enabled to overleap the other men and wind its way into the penetralia of the adverse ranks, and if attacked leap back again within the boundary of its own, has rendered it the favorite Piece of leading players in every country"[26]. This freedom to sidetrack one's trains of thoughts into sundry aesthetic and philosophical directions is also reflected in the writings by the second world chess champion, Emanuel Lasker from later in the century, as in the instance where he tops his digression toward philosophical territories in a book on chess with the following quixotic remark: "What ripens soon, fades soon. To good and weighty theories public recognition comes late. The theory of struggle, divined by men like Machiavelli, Napoleon, Klausewitz, molded by Steinitz in accurate detail for Chess-board, longingly desired by some philosophers, established by myself in universal validity, therefore philosophically, will some day regulate the life of man. I do not in the least hesitate to say so"[27]. Alas, around the same time chess divorced itself from its romanticist past, science started distancing itself from it too and strong, sincere emotions began to be increasingly seen as an adversary instead of a companion of good science. The quantum mechanics and the relativity theory can be said to have been swan songs of a generation of young and starry-eyed scientists who still nurtured the hearts of artists inside them. Everything after this period has belonged to science to which any exhibitions of lyricism became foreign. This is how we have reached today's era, where poetry and lyricism in scientific texts are classified as acts of lunacy and singled out for rapid extermination by the authorities, whichever the form they take – journal editors, peer reviewers, department chairs, tenure committees, funding agencies, corporate R&D sector, and so on.

The game between two Alexanders, Hoffmann and Petrov, played in Warsaw in 1844 is also known as Petrov's immortal and is a paradigmatic illustration of the romantic style. Considering that the first official chess tournaments were held in the 1840s and that the London chess tournament of 1851 was the first international chess tournament, many of the chess masterpieces from the romantic era were played either as parts of impromptu organized matches or in informal private or social settings, and such was the case with Petrov's immortal. The game displays an encounter of heroic inclinations from both players, resulting, expectedly, in a firework of valor that was short-lived and ended with a checkmate in 20 moves only. The game opened solidly, with *Giuoco Piano*, meaning "quiet game" in Italian, but only for the first couple of moves, after which Black sacrificed a knight by taking on f2 to disable the white king from castling. In discovered check, the white king courageously stepped from f2 onto the g3 square instead of retreating to f1, and soon thereafter, White went on to sacrifice his own knight on f7, trying to deprive the black king of his own right to castle (Fig.1). And then a moment of magic struck, with Black coldbloodedly castling, playing the exact move that White wanted to prevent and thus giving away his queen, which the white knight readily captured, at which point Black had a hardly foreseeable forced checkmate in 13 moves, which was executed flawlessly. How deep, in fact, this castling move by Black is may be best illustrated by the fact that the calculation by the leading engines today has to be extensive enough in order for them to see it. Otherwise, Stockfish's initial evaluation, for example, is -4.4 before the 0-0 move by Black and – 8.9 after it. The Elo ratings of these engines are estimated at around 3500, which is as higher compared to the rating of a super grandmaster as super grandmasters' Elo ratings are higher than those of the average coffeehouse player, yet facing a romantic masterstroke like this, albeit played nearly two centuries ago, even they need to think for prolonged periods of time to make sense of it. Castling is usually performed to put the king to safety, but here this move had a dual purpose: aside from protecting the king, it also launched an unstoppable attack on the white king. And when a retreating move has a quiet offensive effect is when we, the aestheticians of chess, know that we are witnessing a very special moment on the chessboard.

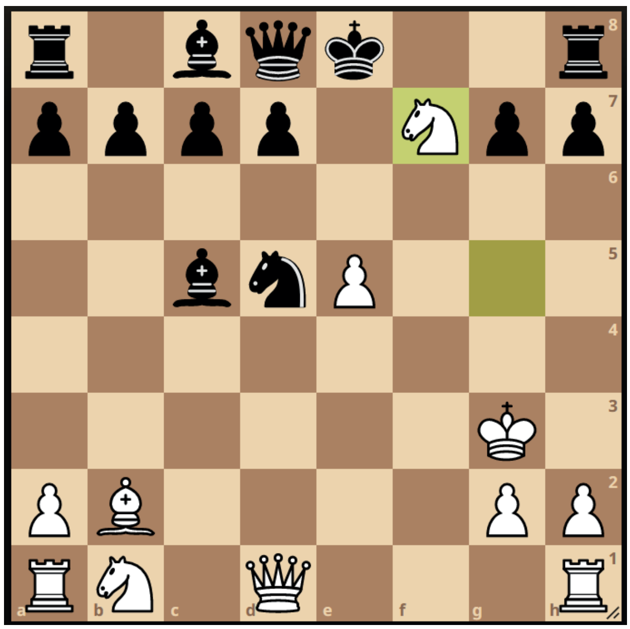

Figure 1. Hoffmann vs. Petrov, Warsaw, 1844, 0 – 1. Position on the board after 12.Nxf7 and before 12…0-0. Black started the game with a display of romantic gallantry, sacrificing a knight on f2, but White deemed it necessary to respond with an even greater dose of audacity and so he went on to push his king closer to the center of the board and then give away his own knight on f7 to prevent Black from castling, which he did anyway, thus creating a position where Black has a forced checkmate in 13 moves.

Seven years after the game between Hoffmann and Petrov was played, in June 1851 in London, in-between the tournament play, Adolf Anderssen and Lionel Kieseritzky played another casual game. In this game, which would eventually enter the annals of chess as the most immortal of all chess games, White sacrificed a number of pawns, a bishop, two rooks and the queen and checkmated the opponent in the end; although this game is elaborated in the course as yet another instance of romanticism in chess, it is skipped here for brevity reasons. A few years down the road from the time Petrov's immortal game was played and only a few months before Anderssen's immortal, the two games exemplifying the romantic era in chess, a scientific experiment chosen to illustrate the era of romanticism in science was performed. It was an experiment conducted by Leon Foucault, first in a cave in January 1851 and then on a bigger scale from the ceiling of the Paris Observatory. Only a few days after the second of the two experiments was performed, on February 3, 1851, Foucault presented his findings at the weekly conference of the French Academy of Sciences and then promptly published them in the Academy's journal, *Comptes Rendus*[28]. A month after the publication, in March 1851, the experiment was repeated on an even grander scale from the top of Panthéon in Paris, and by the end of the summer 1851, as strange as it may seem for the days preceding the instant communication channels of the digital age, the experiment was performed in many cities of the world, including 25 in the United States alone[29].

When Foucault devised the proof of the Earth's rotation with the use of a pendulum, the fact that the Earth rotates around its axis had been known for several centuries. However, for the first time, instead of marking the positions and monitoring the minute movements of planets and stars, the proof of this rotation could come from a simple, everyday object; hence the elegance and the beauty of Foucault's experiment. In simplest terms, the experiment showed that the plane of a swinging pendulum does not go through a full-circle, 360 ° rotation in a sidereal day (23 h, 56 min) at any point on the globe except at the two poles. The angular rate of the pendulum at these two points would correlate directly with the diurnal rotation of the Earth around its axis. At any other point on the globe, the angular rate of the rotation of the plane along which the pendulum swings is equal to the angular rotation rate at the poles (360 °/day) times the sine of the latitude (hence, it is equal to zero on the equator)[30]. This explains why the repeated performances of the experiment in Paris were followed up by performances at numerous other points on the globe in order to arrive at an irrefutable proof of the hypothesis that the pendulum swing correlates with the Earth's rotation around its axis.

Aside from the intrinsic aesthetics of correlating a phenomenon occurring on an astronomical scale and a physical effect occurring on a scale observable with the naked eye, there are numerous other aspects of this experiment that can be instructive and inspirational. For example, 200 years before Foucault's experiment, in the late 1650s, a student of Galileo, Vincenzo Viviani tried to set up a large pendulum for oscillation measurement purposes. Irked by the veering of the pendulum, he used a pair or ropes instead of one to fix its trajectory[31] and prevent the oscillations that Foucault would later use to provide the first evidence of the rotation of the Earth around its axis. This is to say that experimental errors and any deviations from our empirical expectations are to be welcomed with open arms instead of being despaired over, for they usually provide a path toward more extraordinary discoveries than those conforming to the expectations.

In compliance with romanticism elaborated here, Foucault can be said to have exemplified a renaissance scientist with a broad range of interests. This can be illustrated by his wide array of scientific contributions across many topics and disciplines. He started off as a medical student, but later switched to physics because of various medicinal phobias. However, he was unable to find an employment as a researcher and so he worked instead, at least initially, as a journalist, converting major findings from the physics world to popular press reports, which is said to have "contributed to his wide scientific culture and favored his exceptional creativity"[32]. This breadth of knowledge may have helped Foucault to see the pendulum with fresh new eyes, as he, himself, hints at in the opening, 63-word long sentence of his 1851 *Comptes Rendus* paper, which is translated here from French: "The observations, so numerous and so important, of which the pendulum has hitherto been the object, are especially relative to the duration of the oscillations; those which I propose to make known to the Academy have mainly concerned the direction of the plane of oscillation which, moving gradually from east to west, furnishes a sensible sign of the diurnal motion of the terrestrial globe". In other words, practically all experiments with pendulums up to the point of Foucault's work were about measuring the frequency and the amplitude of its oscillations. It is conceivable that the creative propensities and the renaissance background of Foucault helped him view pendulum from a new perspective and look at its plane of rotation instead, specifically how it linked to a physical effect, in his case the diurnal rotation of the Earth. His having only a bachelor degree in science and approaching the latter from a semi-amateurish angle may have been a key factor that endowed him with this flexibility of perspectives and allowed him to propose and subsequently evidence the bold correlation between the swing of a pendulum and the rotation of the Earth. This is by all means an observation that empowers the outsiders because it suggests that everyone, even complete amateurs, can make stunning discoveries with the most grandiose social repercussions if they only start to see the same old things with brand new eyes. Science, correspondingly, need not be a rigid profession where the freedom to profess is conditioned by the conformity to various authorities posed along the academic pyramid. It could rather be a kingdom where everyone is invited to for the investment of their ideas, which, someday, may develop into fruits and treasures that the whole Earth could reap.

On a side note, the undying length of expression, evoking streams of passion bordering complete breathlessness, arising from the want to pack a whole world in each line of text, like that we have encountered in the aforementioned opening sentences of papers by Foucault and Faraday, has a long history of ties with romanticism, perhaps starting with the fact that the first elaborate romantic musical piece, Beethoven's Symphony No.3, Eroica, had its first movement alone longer than the entire typical symphony from the preceding, classicist period. Despite that, Foucault's seminal paper was a brief one, containing hardly over 1,000 words and not a single reference or an equation, let alone a scheme or a figure in its course. The paper only verbally described the observations and provided vague correlations with the prior work by Poisson on predicting the movement of projectiles through the air depending on the latitude. The latitude effect on the rotation of the pendulum plane was the cornerstone of the correlation between this rotation and the rotation of the Earth, yet nowhere in the paper could one find this key formula pop up. Nevertheless, the freeness of expression is authentically romanticist, and the history of music illustrates nicely all the plethora of emotions that were virtually forbidden in the eras of renaissance, baroque and classicism, but then, by the early 19th century, began to be expressed through romantic art. Today, of course, papers of the form like Foucault's would never even be sent out for peer review, let alone published in a technical journal, yet it is this battle against the windmills of the guardians of the gate of scientific publication for the unbound freeness of expression throughout it that has been a perpetual plight in the life of myself as a scientist. This plight I have found to be inherently romantic and many victories, such as those of publishing the first-of-a-kind papers written as a stream of consciousness[33], written in the "reality", diary-like form[34], written as theatrical plays[35],[36],[37], enabling the authorship of the world's youngest author of a scientific paper[38], containing dreamlike sequences[39] or a poetic triptych in their center[40], and comprising amorphous beginnings and ends to reflect the form of creative thought[41], have been nothing short of heroic given the circumstances.

WEEK 2, YEAR 1883: ZUKERTORT VS. BLACKBURNE

Common to the aforementioned immortal games by Petrov and Anderssen, as it was to the games of Paul Morphy, was that both sides in such games opened rapidly, with the obvious idea to go all out to launch an attack on the opponent's king. Such, indeed, was the romantic style of play in the early and mid-19th century. As the century progressed, however, the ideas of positional chess gradually began to solidify in the style of the leading chess masters. The romantic spirit continued to reign, but positional principles were increasingly being employed. The example used to illustrate this can come from the style of Johannes Zukertort, the first player to lose the world championship match, in his case to Steinitz, in the United States in 1886. The game of choice is his immortal, played against Joseph Blackburne at the London tournament in May 1883, which effectively served the role of the world's first candidates tournament, where the players at the first two spots, namely Zukertort and Steinitz, earned their right to play for the title of the world champion three years later.

Compared to most of his contemporaries, who strictly played open games, starting with 1.e4, Zukertort preferred closed games, starting them commonly with 1.c4 or 1.Nf3, which was extremely uncommon in the early 1880s. King's gambit was on his regular repertoire in the 1870s, but in the new decade his preference for closed games became more prominent. To someone not familiar with this fact, Zukertort's occupying one of the two central squares, d4 and e4, only on move 6 of his game against Blackburne would come as very surprising. Zukertort's mode of play was about creating a solid and defensive pawn structure first and only then planning the attack, which is exactly how his game against Blackburne progressed. Black was standing fine until 22…Nxf6, at which point White's patient play exploded into a romanticist blast, involving two decoy sacrifices (Fig.2), first of the queen and then of the rook, and a handful of other spectacular and entertaining moves. However, despite Zukertort's decisive win at the London tournament in 1883, with 22/26 points, ahead of Stein-

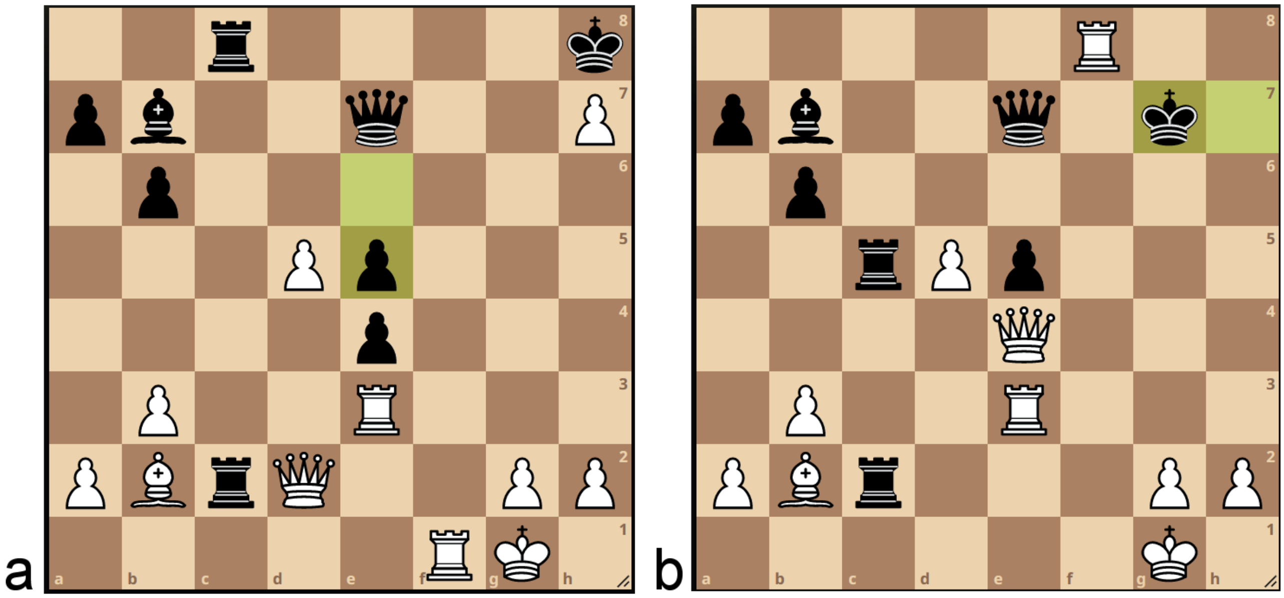

Figure 2. Zukertort vs. Blackburne, London, 1883, 1 – 0. In the position shown in (a), White correctly assessed that Black's pawn in e5 was more valuable than either White's queen or rook, and so he decided to sacrifice first his queen and then the rook to detract the black queen from defending the pawn on e5 by playing 28.Qb4 R8c5 29.Rf8+. Although Black denied both sacrifices, White did not give up and ended the game by enforcing checkmate in twelve with a combined rook and bishop sacrifice in the position shown in (b), playing 31.Bxe5 Kxf8 32.Bg7+, but missing an even more effective checkmate in seven with 31.Rg8+.

Name	Country	Year of becoming the champion	No. of years of being the champion	No. of times defending the title	Dominant style
Wilhelm Steinitz	Germany	1886	8	3	Static
Emanuel Lasker	Germany	1894	27	5	Dynamic
Jose Raul Capablanca	Cuba	1921	6	0	Static
Alexander Alekhine	Russia/France	1927	18	2	Dynamic
Max Euwe	Netherlands	1935	2	0	Static
Mikhail Botvinnik	USSR/Russia	1948	14	2	Static
Vassily Smyslov	USSR/Russia	1958	2	0	Static
Mikhail Tal	USSR/Latvia	1960	1	0	Dynamic
Tigran Petrosian	USSR/Armenia	1963	6	1	Static
Boris Spassky	USSR/Russia	1969	3	0	Dynamic
Robert Fischer	USA	1972	3	0	Dynamic
Anatoly Karpov*	USSR/Russia	1975	10	2	Static
Garry Kasparov*	USSR/Russia	1985	8	3	Dynamic
Vladimir Kramnik*	Russia	2006	1	0	Static
Viswanathan Anand*	India	2007	6	3	Dynamic
Magnus Carlsen	Norway	2013	10	4	Static
Ding Liren	China	2023	0	0	Static

* World champion reigns increase to 15 years for Karpov and Kasparov, 7 for Kramnik and 8 for Anand if disputable years were taken into account. Alexander Khalifman of Russia (1 year), Ruslan Ponomariov of Ukraine (2 years), Rustam Kasimdzhanov of Uzbekistan (1 year) and Veselin Topalov of Bulgaria (1 year) are included amongst the disputable world champions, none of whom managed to defend their titles. Challengers who lost due to the tie rule include Carl Schlechter of Austro-Hungarian Empire in 1910, David Bronstein of Soviet Union/Ukraine in 1951, Vassily Smyslov in 1954, Anatoly Karpov in 1987, and, in the only disputable match, Peter Leko of Hungary in 2004. Challengers who lost in speed chess tie breaks include, in the disputed format, Viswanathan Anand in 1999, and, in the undisputed format, Veselin Topalov in 2006, Boris Gelfand of Israel in 2012, Sergey Karjakin of Russia in 2016, Fabiano Caruana of USA in 2018, and Ian Nepomniachtchi of Russia in 2023.

Table 1. Undisputed world chess champions and the accompanying data.

itz with 19/26, the world championship match in 1886 was won relatively easily by Steinitz, which was mostly owing to Steinitz's outplaying Zukertort in the positional understanding of the game rather than in romanticist tactics. This success of the positional play added winds to the sails of this new philosophy and chess began to drift farther and farther from the exotic romantic lands.

As for science from this period, more and more discoveries were coming out of the work of thinkers who had pure analyticity on their minds, not zested with any artistic appeal. Yet, the romantic spirit was still omnipresent, and one example can come from the two scientists who proposed the black body radiation law in 1884, a year after the London chess tournament was held, aka the Stefan-Boltzmann law. The older of the two, Jožef Stefan was a Slovenian physicist, who, as not many people know, was equally engaged in poetry writing as he was in research in physics. Lest this be forgotten, a quote of his that I cited in my PhD thesis, which was, coincidentally, defended at the Slovenian institute bearing his name, said the following: "Practical field is still large, and a lot else is needed for the growth of our people. However, to write such books is a hard thing; we need people who have science in their heads and love in their hearts"[42]. At another place, Stefan made the following romantic observation: "If a man thinks about the connections in his natural surroundings, if he is careful about the feelings that come to him during observations of natural objects and reflections on them, when he walks through the woods, fields and valleys, when he climbs the hills, he may find many threads that link his heart to sensibility and thinking in accordance with nature. And the more he knows about these links, the more he penetrates into knowing oneself. Therefore, in order to know, we need to unravel all the aspects of our spiritual living. If we want to get to the whole, we ought to start from the parts"[43]. Three years later, in 1877, Stefan's student, Ludwig Boltzmann derived one of the most fascinating equations in science, namely the statistical definition of entropy (S), $S = k \cdot \ln W$, where k is Boltzmann's constant and W the number of possible states of the system with an equal energy. One revolutionary aspect of this equation, which is all that is inscribed on Boltzmann's tombstone in the Viennese Zentralfriedhof, was that it provided a definition of a physical quality that had a purely thermodynamic meaning from a completely different, statistical point of view. Entropy, from that moment on, was no longer a heat-related quantity alone, but rather one that can be used in innumerable physical and abstract contexts. From the realm of science, entropy suddenly entered the vocabularies of poets and philosophers and even laymen. To see a physical quality from a completely new angle and to bridge with a single equation two distinct disciplines, in this case thermodynamics and statistics, may be enough to grant Boltzmann's definition of entropy the title of perhaps the greatest equation ever derived. Yet, this bold romanticism of creating one's own language to describe events standardly described using another, more traditional language, was just about to disappear from the world of science for good.

WEEK 3, YEAR 1895: STEINITZ VS. VON BARDELEBEN

As the 19th century was coming to an end, romanticism started to fade away, in chess, science and art alike. The era of the subtle accrual of positional advantages was born, the major proponents of which were the likes of Tarrasch, Paulsen and the first undisputed world chess champion (Table 1), Wilhelm Steinitz. Sacrifices on the board simultaneously became rarer and more subtle and adjusted as such to the contemporary aesthetics, one example of which comes from Steinitz's game against Curt von Bardeleben played at the Hastings tournament in 1895. A particularly momentous move in this game was the giving away of the central pawn with 17.d5 (Fig.3), whereby White opened the space for his knight and file for the rook and created conditions for an unstoppable attack on the black king. The game ended in a very illustrious manner, with the black king being forced to move, funnily, from e8 to f8 to g8 to h8, the very corner of the board, with 21. Ng5+ Ke8 22. Rxe7+ Kf8 23. Rf7+ Kg8 24. Rg7+ Kh8 25. Rh7+, after which Bardeleben, who was second in the lead at the tournament by that point, having scored 7.5 out of 9 possible points, simply walked out of the hall, without officially resigning. Although this has been unequivocally denounced since then as an act of poor sportsmanship, I have always considered it more of a classy and humorous act; after all, where else could he, the king go except beyond the board and out of the room and then who knows where after this masterful sequence of moves pulled off by Steinitz?

In science around this time, the robustness and accuracy of experimentation became increasingly important, which marked a new dawn, namely that where imagination soaring on the wings of pure fancy and little material resources started ceding place to superior technical advances. One experiment particularly nicely illustrates this: the Michelson-Morley experiment of 1887. The beauty of this experiment is multifold, one aspect of which stems from the wittiness of the experimental design and another one of which stems

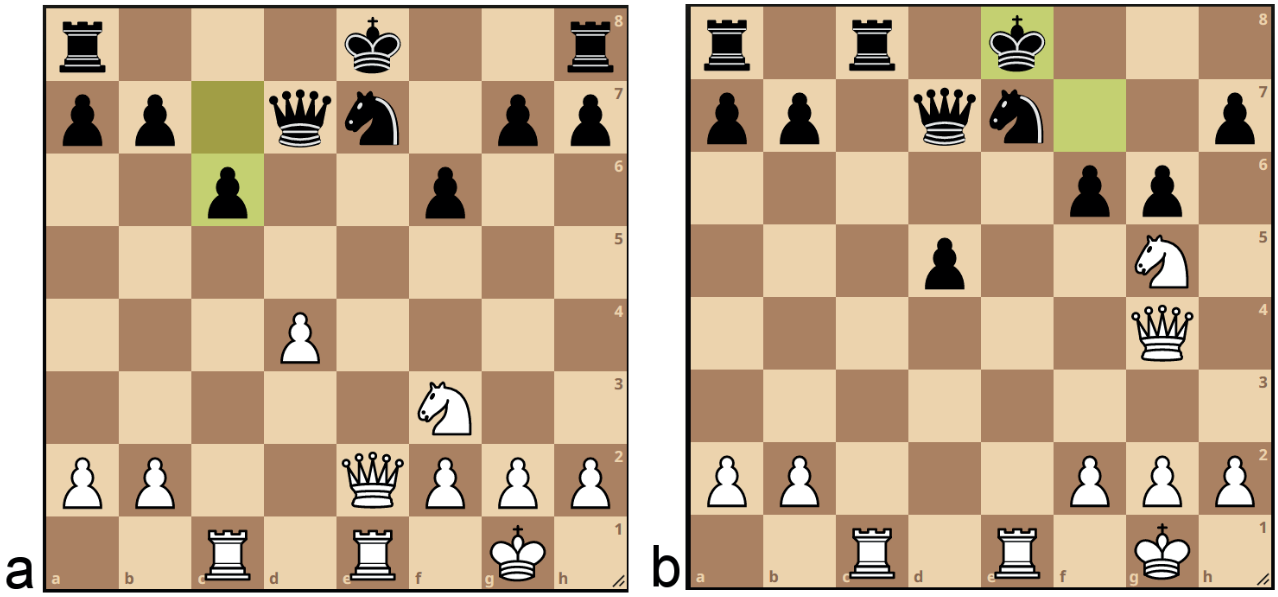

Figure 3. Steinitz vs. von Bardeleben, Hastings, 1895, 1 – 0. Position shown in (a) is after 16…c6 and before 17.d5 cxd5 18. Nd4. Steinitz's pawn sacrifice in the center was dynamic, giving away the center completely in return for a gained initiative, but it was also rooted in rigorous tactical calculations, as the capture on d5 by the pawn on c6 loses by force, just as well as the only other reasonable move, the unpinning of the king with 17…Kf7, does. Position shown in (b) presents the starting point of the black king's forced walk along the edge of the board and into its corner with 22.Rxe7+ Kf8 23.Rf7+ Kg8 24.Rg7+ Kh8 25.Rxh7+, at which point von Bardeleben exited the room without resigning the game, hinting wittily – or madly – at the ever present analogies between chess and life.

from its still being considered the most important failed experiment in the history of science. The experiment was conducted in the attempt to prove the existence of aether, the elusive medium that was thought back then to exist and fill up the physical space so as to enable the propagation of light waves. The premise behind the experiment was that, in partial analogy with Foucault's experiment, if the Earth traveled through aether, the speed of light would differ depending on whether the light wave propagated parallel to the flow of aether or perpendicular to it. Hence, the two experimenters spent years assembling an interferometer with the path length of eleven meters, which would be able to bounce light waves between mirrors in perpendicular directions, yet to their dismay, no difference between the speed of light sent back and forth in the vertical direction and that sent in the horizontal direction was ever detected. The experiment ended up being considered a monumental failure for the next fifty years, at which point it was turned into a key evidence in favor of the theory of relativity, which derives the relativism of physical properties such as mass, length and time directly from the constancy of the speed of light in all physical systems and under all conditions. To this day, the Michelson-Morley experiment represents a paradigmatic example of how the results of a failed experiment can turn into invaluable findings once the context of their interpretation becomes enlarged or transposed to a different empirical domain. The search for an immaculate precision of measurements by employing robust, state-of-the-art instrumentation, thus, unexpectedly, found its greatest use not for enabling a new practical application, but rather to gain support for the revolutionary abstract model that the relativity theory was.

WEEK 4, YEAR 1914: LASKER VS. CAPABLANCA

As the 20th century rolled around, chess began to be increasingly approached as science, with the similar rigor and analyticity, most notably through contributions by the likes of Tarrasch, Steinitz and Nimzowitsch. With this strict analytical approach to chess, the purely combinatorial play from the days of romanticism started to cede place to positional play and play based on strategic principles proven in practice. The emergence of the second and the longest reigning world champion, Emanuel Lasker, however, coincided with an amalgamation of these two fundamentally different styles. The American writer, Fred Reinfeld divided the

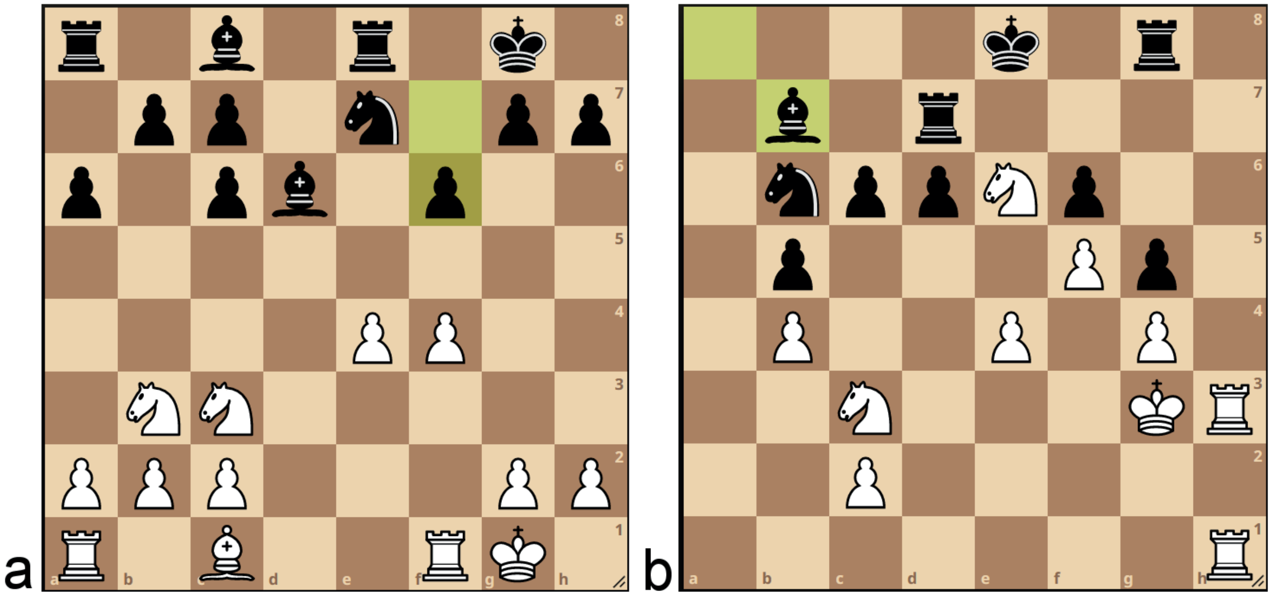

Figure 4. Lasker vs. Capablanca, Saint Petersburg, 1914, 1 – 0. After Capablanca played 11…f6, Lasker decided to create an outpost for Black's pieces on e5 and undouble his pawns by playing the seemingly friendly 12.f5 b6 13.Bf4 Bb7 14.Bxd6 cxd6 (a), and only then, when the opponent had been lulled, deliver the blow with the unexpected pawn sacrifice, 35.e5 dxe5 (b), which would open the space for the white knights to enter Black's fortress and ravage it.

approach to chess at the turn of the 20th century to that proponed by Steinitz, "amenable to order, logic, exactitude, calculation, foresight and other comparable qualities", and that advocated by Mikhail Chigorin, "full of disorder, imperfection, inexactitudes, fortuitous happenings, unforeseen consequences", the former striving to impose order upon the irrational and "trying to banish the unforeseen" and the latter going to the other extreme, taking delight in the unpredictable. Based on this dichotomy, Reinfeld went on to observe that Lasker "combined the objective laws of Steinitz and the subjective viewpoint of Chigorin"[44].

Unsurprisingly, the ascent of Lasker to the throne of the chess kingdom coincided with the groundbreaking discoveries of quantum mechanics, which accordantly showed that science, traditionally seeking order in Nature, has no choice but to embrace the stochastic, the probabilistic and the irrational. At no time before or after did science make an entry into territories of an equivalently rich philosophical and metaphysical relevance, let alone mystical, as then. Another key finding of the quantum theory came from its demonstrating an inevitable influence of the observer of any physical event on its evolution and, correspondingly, the subjective bias engrained in every statement, regardless of how perfectly neutral and objective it may seem. Lasker's style is congruent with this fundamental principle revealed at the beginning of the 20th century through the framework of quantum physics by being allegedly the first chess player of the champion caliber to consciously alter his playstyle with respect to the personality and style he faced on the other side of the board, sometimes playing in the style of his opponent to relax him before delivering a deadly blow and sometimes playing dubiously and perplexing him from the start with strange variations. For example, compelled to win as White the game against Capablanca at the tournament in Saint Petersburg in 1914 in order to retain chances of getting ahead of his rival, who was leading by one point two rounds before the last, Lasker opted for an unexpected exchange variation of the Ruy-Lopez, which is known to allow for a comfortable play for Black and easy equalization, then opened the e5 outpost for Black with the strange and unorthodox 12.f5 (Fig.4a) and undoubled the black c pawns by exchanging bishops on d6, and only then, in nearly the endgame, played the stunning positional king's pawn sacrifice (Fig. 4b) to surprise the opponent and secure a win.

One year after this encounter between Lasker and Capablanca, an exemplar of a scientist with multidisciplinary outlooks, D'Arcy Thompson wrote *On Growth and Form*, the publication of which was delayed by several years due to World War I[45]. In the context of the course built around analogies between chess and natural sciences, it is natural to select this notable work by Thompson for in-class discussion because it is a classic treatise on analogies in form between different organisms and natural objects. Thompson was mesmerized by the beauty of the natural world and his writing was motivated by the craving to explain its forms, which is obvious from him surpassing even Michael Faraday in the usage of the words "beauty", "beautiful" and "beautifully", which appear whole 102 times in the book, one occurrence of which was used to praise Faraday's aforementioned experiment on vibrating beds, calling it, simply, "beautiful" in one of the footnotes. Because of its spanning multiple disciplines due to the power of analogies, the book inspired developmental biologists, mathematicians, solid state chemists, architects, anthropologists, computer engineers, and thinkers from many other niches.

WEEK 5, YEAR 1921: ALEKHINE VS. TEICHMANN

As era of one style slowly transitions to that of another, the transitional times are often marked with juxtapositions of the two styles, and such was the case with Emanuel Lasker. He understood that studying chess with scientific rigor is the way of the future, but he also kept the romantic spirit alive, all along with the appreciation of mysticism and irrationality as the driving forces leading toward excellence in performance. As the best illustration of the pivotal traits of his style, we could refer to the description of it by his chess contemporary, Richard Réti: "With the perfect technique in chess that is dominant today, a peaceful, correct play almost always leads to draw. To avoid that, with theoretically wrong moves, Lasker would draw himself onto the very edge of a cliff. However, owing to his exceptional strength, he succeeds in clinging onto this edge while tossing the opponent down the abyss"[46]. Lasker developed the habit of playing moves that engines might classify as mistakes or inaccuracies, as it is with 12.f5 in Fig.4, but were in reality puzzles for his opponents, putting the positions in states of imbalance, from which complexities ensued and a player with the greater foresight and positional fluency would emerge as a victor. This principle, however, could be said to have culminated a decade or so down the timeline of chess history, in the playstyle of Alexander Alekhine, who intuitively understood that midddlegame wizardry could be put to display only insofar as the balance of the static position is disrupted, with the caveat that this disruption inevitably proceeds at the cost of destabilizing one's own position to some extent. Even further down the road, the 8th world chess champion, Misha Tal would convert this principle into an allegory talking about one player, that is, usually him, taking another into "a deep dark forest where 2 + 2 = 5 and where the path leading out is only wide enough for one"[47]. One example from Alekhine's oeuvre may be his game against Bogoljubov in Hastings in 1922, one of the most outrageous games ever played at the top level, in which Black, that is, Alekhine, sacrificed three queens and two rooks to end up with a single pawn advantage in a king and pawn endgame. A less known example, but more illustrious for the concept at hand, may come from the game Alekhine played against Richard Teichmann in Berlin in 1921, where he deliberately gave away his f pawn for the more centralized king in a rook and bishop endgame (Fig.5), having correctly assessed that this would give him a decisive advantage. Today, with the use of computers we could assess the position after the loss of the pawn as nearly equal, but with a slight advantage for White, attesting to the correctness of Alekhine's calculation. In all, the fourth world champion mastered throughout his career a remarkable and unprecedented skill to execute towering middlegame conceptions, both positional and combinatorial, by first creating deliberate complications on the board.

In the science world, this idea of disruption of the static equilibrium in order to breathe life and sneak an opportunity for a victory into a position is best illustrated by the principle derived a couple of years after this game was played, in 1927, by Werner Heisenberg. This relation, known as the uncertainty principle, presents possibly the most fundamental and important physical equation ever derived. Ironically and symbolically for the quest of all the world's sciences and philosophies toward perfect knowledge, this equation is an inequation and a statement of the fundamental impossibility of arriving at the perfect knowledge about anything. According to this inequation, *i.e.*, $\Delta x \cdot \Delta p \geq h/4\pi$, the more precisely one measures the momentum of a system, the less precisely one can measure its trajectory, and *vice versa*; or, as another formulation of it has it, *i.e.*, $\Delta E \cdot \Delta t \geq h/4\pi$, the more precisely one measures the energy of a system, the less precisely one can measure its temporal component, and *vice versa*. In broader frames, this is to say that the ideal of Laplace's omniscient, demonic computer and of perfect knowledge of anything is illusory and that irrational intuitions must be embraced as essential complements of stringent calculations in order to come up with perfect knowledge, the perfection of which will be, understandably, conditioned by its perfect imperfections.

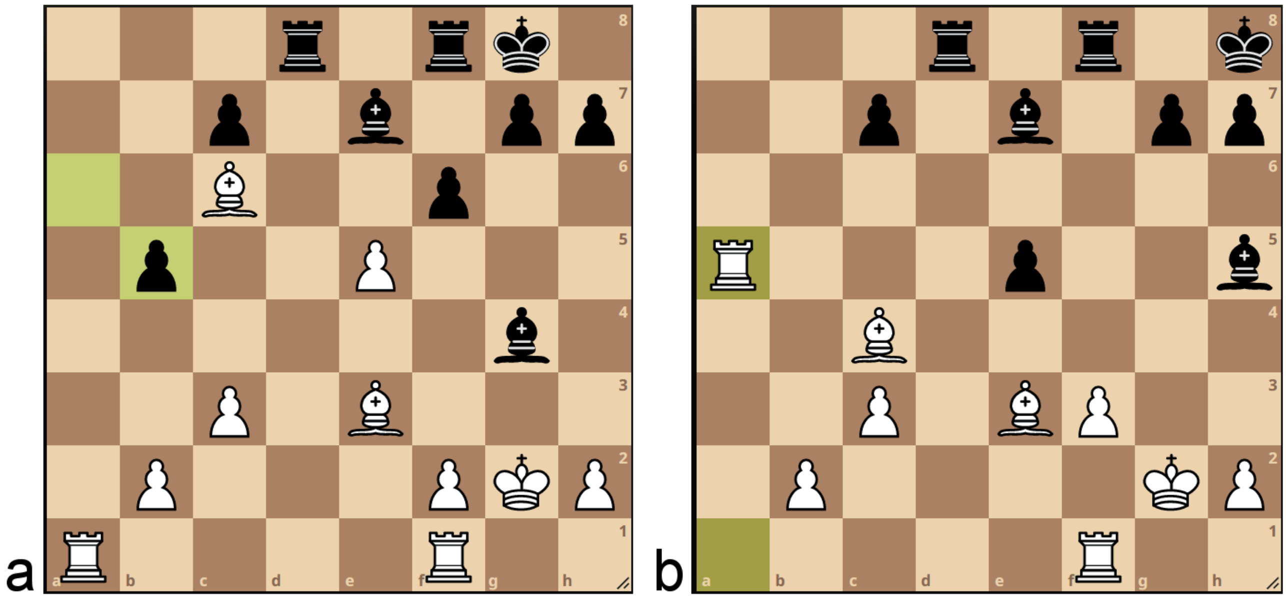

Figure 5. Alekhine vs. Teichmann, Game 4, Alekhine - Teichmann Match, Berlin, 1921, 1 – 0. Position shown in (a) is before 19.Bxb5 fxe5. White realizes that maintaining the material equality on the board, even at the cost of swapping its sole central pawn with a black pawn, gives White a better position than capturing the pawn on f6 and giving Black an extra tempo in activating its f file rook. This activation of the rook by bringing it to f6 square would lead to an unstoppable discovered check threat following 20…Rg6 if White immediately takes on both f6 and b5 (19.exf6 Rxf6 20.Bxb5), which would be instantly losing for White. Position shown in (b) is after 22.Ra5 and before 22…Rd1 23.Bd5 Rxf1 24.Kxf1 Bxf3 25.Bxf3 Rxf3+ 26.Ke2. Alekhine's dynamic nature comes to full prominence in this materially equal endgame position, where he sacrifices the f3 pawn for a more centralized king, having correctly assessed that one such exchange would increase the winning chances for White.

WEEK 6, YEAR 1927: ALEKHINE VS. CAPABLANCA

Jose Raul Capablanca went down in chess history as the first world champion and perhaps the world's first top player to whom poetics of pieces matter nil and all in his sphere of interest was the elicitation of technical precision *en route* to a cold and mechanical victory. He was gifted with the ability to see how minor and seemingly negligible middlegame maneuvers could convert to a small but accruable advantage as the game progressed toward the endgame. A special class of moves that he mastered and generously employed were those with dual purposes, having recognized not only how a simultaneous attack on two distinct squares in the opponent's position is hardly defendable against, but also how much tempo can be gained by playing moves that serve both offensive and defensive roles. One such exemplary multipurpose move may be 14.Qf3 from the game Capablanca played against Frank Marshall in New York in 1918, with which the white queen attacked the black rook on a8, blocked the development of the black light-squared bishop to b7 and protected the white kingside, all at once. Notably, this was the game in which Marshall played the gambit in the Ruy-Lopez opening now known under his name; 'twas the gambit he had prepared for a whole decade prior to this game and then lost it due to Capablanca's immaculate defense.

As fate would have it, however, this exact multimodal style of play pioneered by Capablanca was eventually employed against him, nowhere more efficiently as in the game that ended his time on the throne of the chess world, the last one from the world championship match he played against Alekhine in Buenos Aires in 1927. In his autobiographic annotation, Alekhine particularly commended the quiet sidestep of his queen from e2 to d2 on move 21 (Fig.6), with which he eyed the weak pawns on a6, e5 and h6 at once, being ready to strike on the queenside, the kingside or the center depending on the circumstances. Specifically, if Black were to deploy a counterattack with 21…Bc6, Alekhine was ready to play 22.Nh4, as after 22…Nxe4, White wins with 23. Nxf5+ gxf5 24. Nxf5 Kf6 25. Qxh6+ Kxf5 26. g4#, and after 22…Bxe4, White plays 23.Qe3. In the game, Capablanca deemed it wisest to give away the a6 pawn after White's dual attack on the pawns on a6 and e5 with 23.Qa5 and allow White a passed pawn on the queenside in return

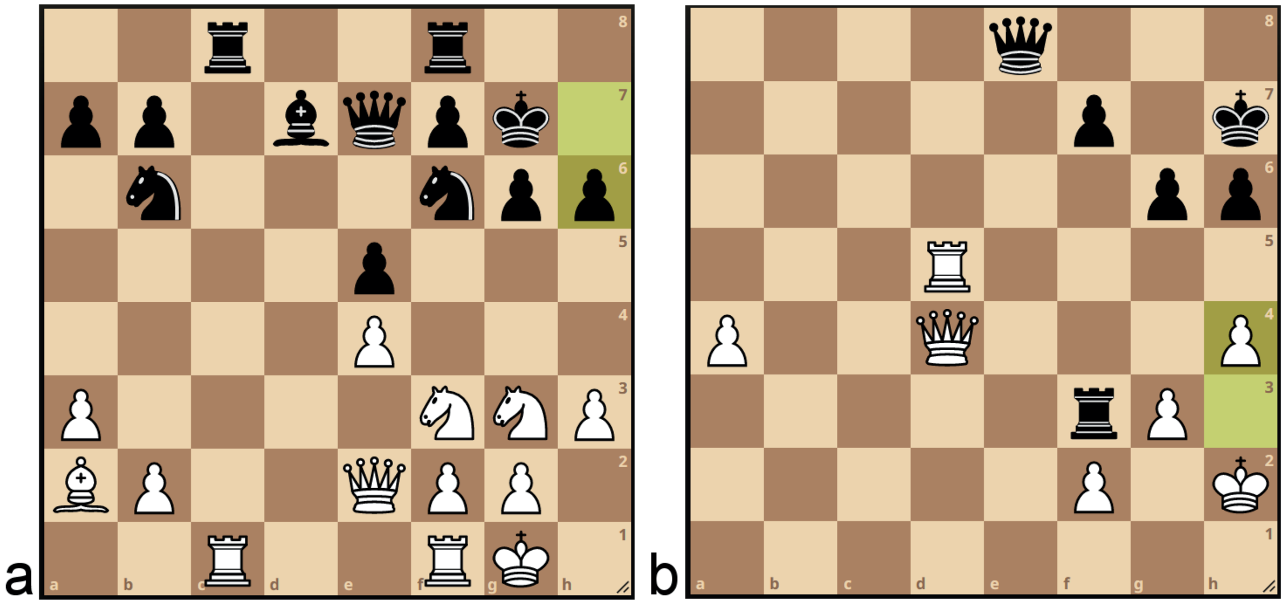

Figure 6. Alekhine vs. Capablanca, Game 34, World Championship Match, Buenos Aires, 1927, 1 – 0. After Capablanca played 20… h6, just subtly weakening the pawn structure around the black king, Alekhine, in response, played quiet 21. Qd2 in the position shown in (a), posing a triple long-term threat against Black's queenside, kingside and the weak central pawn. One extra pawn in a queen and rook endgame became winning only after Alekhine's fine maneuver with which he first denied the exchange of queens on h8 and then enforced this exchange three moves later: 46…Qh8 47. Qb6 Qa1 48. Kg2 Rf6 49. Qd4 Qxd4 50. Rxd4 (b). The only difference was that in the former case the black rook would have stepped behind the passed pawn on the a file, whereas in the latter scenario it had to step in front of it. This subtle difference executed very much in Capablanca's style imparted a decisive advantage onto Alekhine and won him this four-day long game and the world champion title. Of note is also that White's 48th move, quiet 48.Kg2 was not only the one and only winning move in the position, but all the others were instantly losing, too, except for 48.h5, which would have led to a draw, at least in theory.

for an initiative, but Alekhine precisely predicted, in Capablanca's style, that the endgame grind would be winning for White, and so it was, after no less than 82 moves.

Having brought to mind these moves with dual purposes, it is not coincidental that on this very same year, 1927, Davisson and Garner would perform Young's double slit experiment with electrons and demonstrate that, like light, so do elementary particles have both particle-like and wave-like properties, being describable by de Broglie's relation of equivalence between the mass and the wavelength, *i.e.*, $\lambda = h/mV$. And then, a year later, in 1928, Paul Dirac derived the relativistic wave equation applicable to all mass particles with the spin of ½, including quarks and electrons susceptible to the symmetry operation known as parity inversion, thus effectively predicting the existence of antimatter, alongside referring back to Alekhine's strategy of mirroring the style of his opponent to provoke his loss and dethronement.

WEEK 7, YEAR 1930: STÅHLBERG VS. KHAN

In the years following World War I, a positional theory in chess, more radical than any other proposed before or after, began to emerge from the studies by the central European players including Aron Nimzowitsch, Richard Réti, Ernst Grünfeld and others, known by the name of hypermodern theory. The dominant view at the time, crafted along the lineage extending from Philidor to Steinitz to Tarrasch, held that the goal of the opening is to control the center with pawns. The hypermodern theory challenged this view and asserted that this is not needed and that the control of the center with minor and major pieces and only then breaking through the center with pawns presents the right positional approach. As a result, a number of hypermodern openings began to pop in the 1920s, ranging from the soft, such as the Nimzo-Indian defense, to the extreme, such as the four pawn attack variation of Alekhine's defense. The hypermodern theory was short-lived in its full form, but some of the positional principle it insist-

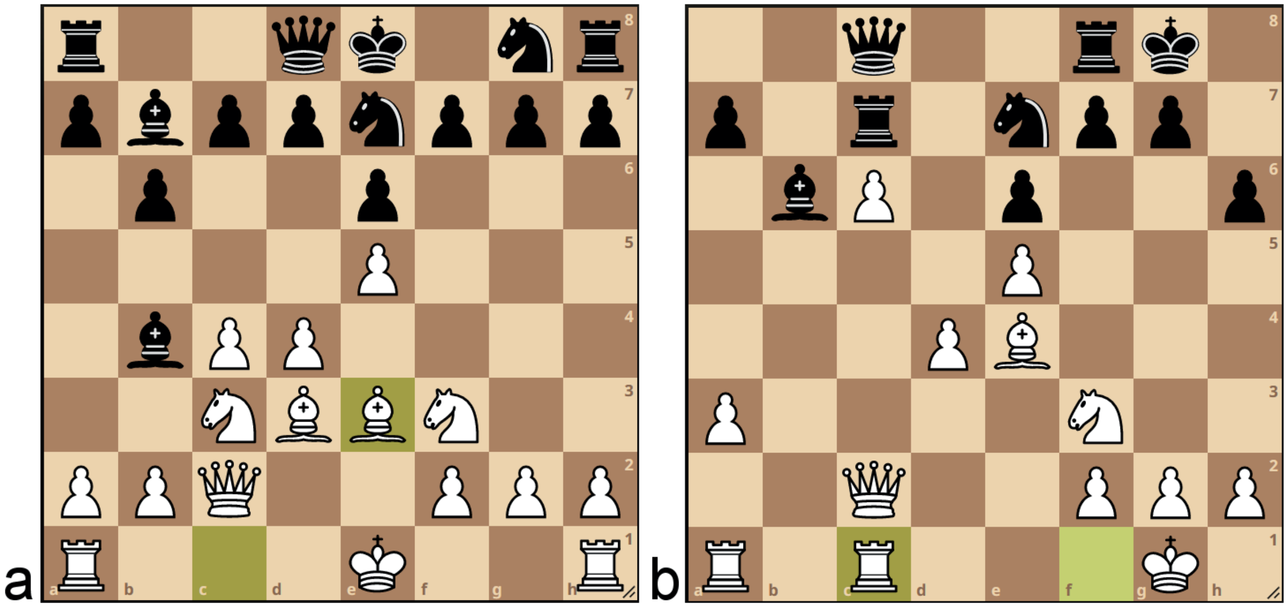

Figure 7. Ståhlberg vs. Khan, Prague Olympiad, 1931, ½ - ½. Khan follows the hypermodern principle of leaving the center to the opponent's pawns and then undermining them from the side by opting for a dynamic play involving a pawn sacrifice in the position shown in (a): 9.…b5 10.cxb5 Nd5. By move 23, Black is two pawns down, but is saved by another instance of undermining the center occupied by white pawns, playing 23…f5 24.exf6 gxf6 in the position shown in (b), which helped him finally acquire a counterplay and secure a draw.

ed on continued to pervade the later schools of positional chess. Still, today, this theory mostly serves as a testament to the rule-breaking thought that marked the given era, not only in chess, but in arts and sciences as well. These days, however, a theory as radical as the hypermodern would never be embraced by the chess pundits, nor would its analogs be adopted by the scientific community either, but a 100 years ago the openness to such innovative stances was evidently greater than today. For example, according to a general consensus among the editors of the world's most prestigious scientific journals[48], Einstein's theory of relativity, proposed in the same decades that saw the birth of quantum mechanics, given its radical theoretical outlook without a solid empirical evidence, scanty referencing and obscure affiliation, would not see the light of the day in any of these journals today. It is disheartening to realize that one century ago the climate was more open to paradigm-shifting ideas than it is today, but truth, in the words of the chess analyst, Ben Finegold, hurts, if not, as the Danish philosopher Søren Kierkegaard had it[49], paralyzing the one who comes face to face with it. What drives the innovation in sciences and technologies today is not an intellectual climate more conducive to creative thought, but only the more massive investments in research and development, where the mantra of 3 %, that is, the expectation that 3 % of research funded will lead to practical innovation, holds the central place. Without much dedication to train scholars in innovative thinking from the basic educational levels onwards and with thinking instead that wealth is sufficient to generate new knowledge, however, this innovation pyramid will continue to stand on shaky legs and the most creative mindsets will continue to slide down its edges and fall into the mud while the skilled entrepreneurs and sly self-promoters will keep on climbing to the top. Yet, we should remember that there were times when openness to innovation was greater than it is today, and, as we see from this argumentation, it was present in parallel in both the worlds of chess and of science.

Like the leading art movements of the early 20th century, be they cubism, Dadaism, fauvism or futurism, the hypermodern theory was short-lived in its essence. Logically, therefore, the illustration of it calls for the reference to an equally short but illuminative chess career, which will be that of Sultan Khan, a native Punjabi who won the British chess championship in 3 out of 4 attempts and who achieved victories over many notable players, including the world champion, Capablanca, at the tournament in Hastings in 1930/31. After a couple of years he spent in Europe, though, Khan returned to his homeland, where chess was not as popular, and worked as a farmer for the rest of his life. In this example, Khan, playing as Black against Gideon Ståhlberg of Sweden[50], shows what was meant by the hypermodern idea of eyeing the center with the minor pieces and only then breaking through the center, which he attacked by playing 9…b5 in the position in Fig.7, thus sacrificing a pawn in order to create an outpost for his knight or bishop on the central d5 square. This outpost, however, in the game, was utilized very shortly, as the advance of the white queenside pawns proved the sacrifice dubious, illustrating how ideas in chess and life alike can be beautiful, but also crumble under the feet of bandwagon-chasing pedestrians. Anyway, like the careers of Paul Morphy before him and Bobby Fischer after him, Khan's was short-lived and he withdrew at the peak of his prowess from the chess world. He made his journey from the British Raj to England at around the same time when a fellow Punjabi, Subrahmanyan Chandrasekhar made the same trip, on which he derived what is today known as the Chandrasekhar limit and predicted the existence of black holes, but then ended up being ridiculed when he presented those findings to the Royal Astronomical Society of the UK. However, unlike Chandrasekhar, who had a healthy habit of moving each decade to a new topic of study and leaving all the preceding research behind him, Khan left chess for good upon his return to Punjab and devoted himself to the tending of, literally, greener pastures. Similarly, there have been countless scientists who have left brief but impressive marks on their fields, even though the public and the peers have never heard of them. Very often, whether it was due to their modesty and being fed up with the various toxicities and injustices abundant in the scientific community, the incongruence of their ideas and models with the reigning paradigms, the natural tendency of creative masterminds to clash egos with the authorities and later be discarded by them, or some other unforeseeable reason, they left the world of science prematurely. In the end, what the fate of the hypermodern theory shows is that radical ideas may spur creativity, but may also be destined for prompt marginalization, if not a drift straight into oblivion.

WEEK 8, YEAR 1947: EUWE VS. NAJDORF

World War II had a profound influence on virtually every scientific and nonscientific field and discipline. Perhaps most significantly for this discussion, the urgency of defeating the enemy in this war necessitated the recruitment of a workforce directed to produce practical and tangible technologies based on the preexisting scientific concepts in lieu of exploring new abstract and theoretical concepts. This stance coincided with Franklin Roosevelt's founding the Office of Scientific Research and Development in June 1941, with the objective of dividing federal research funds between government, academic and industrial sectors with one single objective in mind, summed in the words of the inaugural director of this office, Vannevar Bush: "Will it help to win a war; this war?"[51] The period following World War II was, then, that of a grand awakening into an age of relativism as a natural response to the suddenly risen awareness of the dangers of the intrinsic totalitarianism of all ideologies, be they called fascism, communism or something else. In 1955, Carl Theodor Dreyer would film *Ordet*, a remarkable movie where the prophet becomes a healer only after he shuns any mystical presumptions and becomes an ordinary citizen, reflecting the zeitgeist of these times. This emphasis on the merits of pure rationalism can be illustrated by the style of the 5th world chess champion, Max Euwe, who is said to have directly transcribed his skills as a mathematician to the chessboard and thus played in a very dry, but precise way. Of course, as with every chess player, when an opportunity to launch an attractive attack arises, they would attack, and so did Euwe too, as in his notable games against Szabo in Groningen in 1946 or against Tartakower in Venice in 1948. However, the example shown in Fig.8 comes from the opening, Round 1 game Euwe played at the tournament in Mar del Plata in 1947, against the local favorite and the best Argentine player in history, Miguel Najdorf, who, himself, was a World War II refugee from his native Poland. Najdorf, namely, found himself at the chess Olympiad in Buenos Aires in 1939 when Nazi officers arrested his entire family and confiscated all his property, and so he decided to stay in Americas, playing record-setting simultaneous blindfold chess games in hopes that the news of him being well would reach his family. In this game, Najdorf launched a fierce attack as Black, but Euwe defended precisely and at the right moment returned the exchange sacrifice (Fig.8) to secure the winning advantage. In recognition of his orthodoxy, in 1970, the World Chess Federation (FIDE) would appoint Euwe as its president, who to this day represents the most successful chess player to have held such an esteemed position in the world's main chess organization. Creative renegades, of course, are never deemed appropriate for such functions, unlike the rather formal and moderate individuals, as Euwe was, on and off the board. Transposed to the scientific domain, this type of leadership spurs conformity and toeing the line of tradition instead of reveling in exploration of revolutionary novelties. Expectedly, the post-World War II era brought about the rise of Mikhail Botvinnik to the

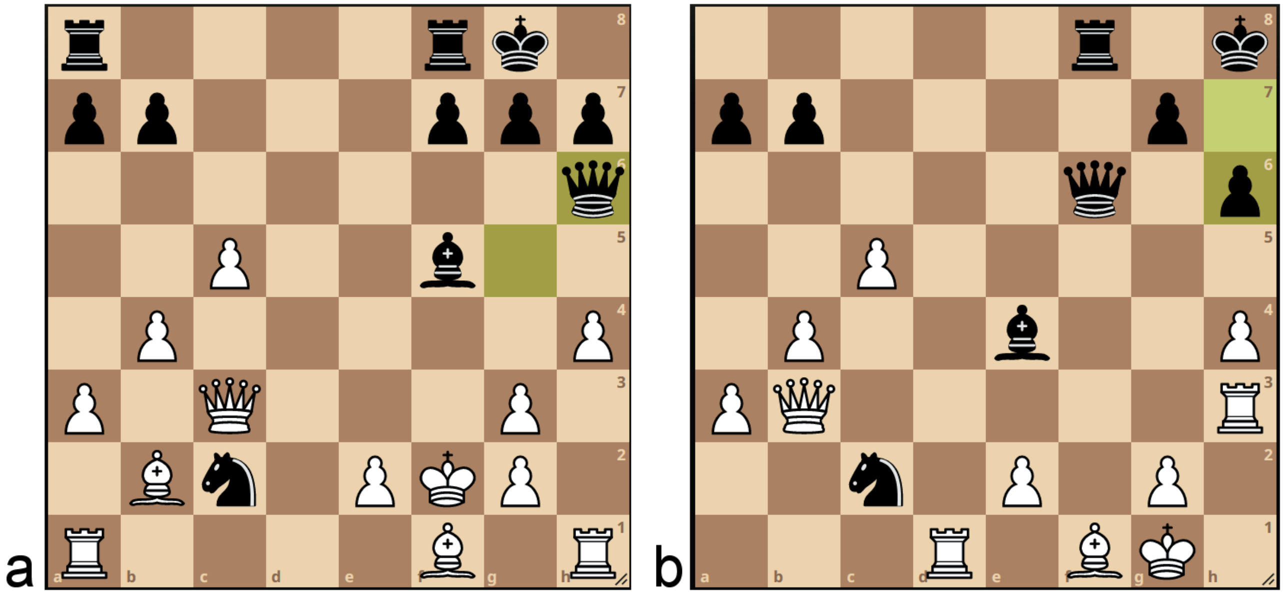

Figure 8. Euwe vs. Najdorf, Mar del Plata, 1947, 1 – 0. Euwe peters out the resilient attack by the black pieces, first by playing 18.g4 in the position shown in (a), having realized that the white king would find a safe harbor after 18…Bxg4 19.Qxc2 Qf4+ 20.Kg1 Qe3+ 21.Kh2 Qf4+ 22.g3 Qf2+ 23.Bg2, and then, in the position shown in (b), by choosing to return the exchange sacrifice at the right moment, playing 26.Rf3.

top of the chess world and marked the period of solidity and logicality in not only the dominant chess style, but also the mainstream mode of doing science. The opening preparation and play by the principles instated themselves as the central and only possible approaches to chess, whereas play for play's sake, for uplifting the spirits of the gazers and for earning insights into the deep nature of creativity was sidelined in Botvinnik's method. At the same time, in natural sciences, the smidgeons of the romantic spirit were shunned as Dionysian and Wagnerian traits that were deemed dangerous and capable of only causing problems in a domain that is to be composed of pure logic, untainted by any dark intuitions or emotions. When one form of tyranny is uprooted, another one, as a rule, instills itself somewhere else, and science has yet to recover from this expulsion of the great romantic spirit from it that has happened to a most drastic degree in these decades and that continues to this very day.

The romantic streams in the realm of science of this time continued to exist, albeit shyly. Rather than being bluntly suppressed, as it is the case today, they were more channeled into logical means of expression. One such case was with the early cybernetics movement, which was being given birth to at the Macy conferences on cybernetics, held between 1946 and 1953 in the Upper East Side of New York City. As influential as the Solvay conferences on physics earlier in the century, the Macy conferences enabled prolific congregations of intellectuals, many of whom were romanticists at heart, but who channeled this romanticism into the effort to create a whole new field of science, which would, even more importantly, provide an outlook on every other field of science imaginable. This metalogical aspect of cybernetics was particularly notably elaborated by Gregory Bateson[52] and by the second-order cybernetic models of Heinz von Foerster[53], along with their ardent methodological followers[54],[55],[56]. In all, with their work, these giants carved cornerstones of today's computer science and information technologies, but what is especially important for this discussion is to note how frequent their excursions to the spheres of philosophical thought were upon conceiving and refining their scientific models and worldviews. This is to say that romantic aspirations were starting to be subdued and sublimed, and their free expression became less socially acceptable than ever before in history, even though they continued to live as a powerful undercurrent, conforming to Gregory Bateson's adage: "There seems to be something like a Gresham's law of cultural evolution according to which the oversimplified ideas will always displace the sophisticated and the vulgar and hateful will always displace the beautiful. And yet the beautiful persists"[57].

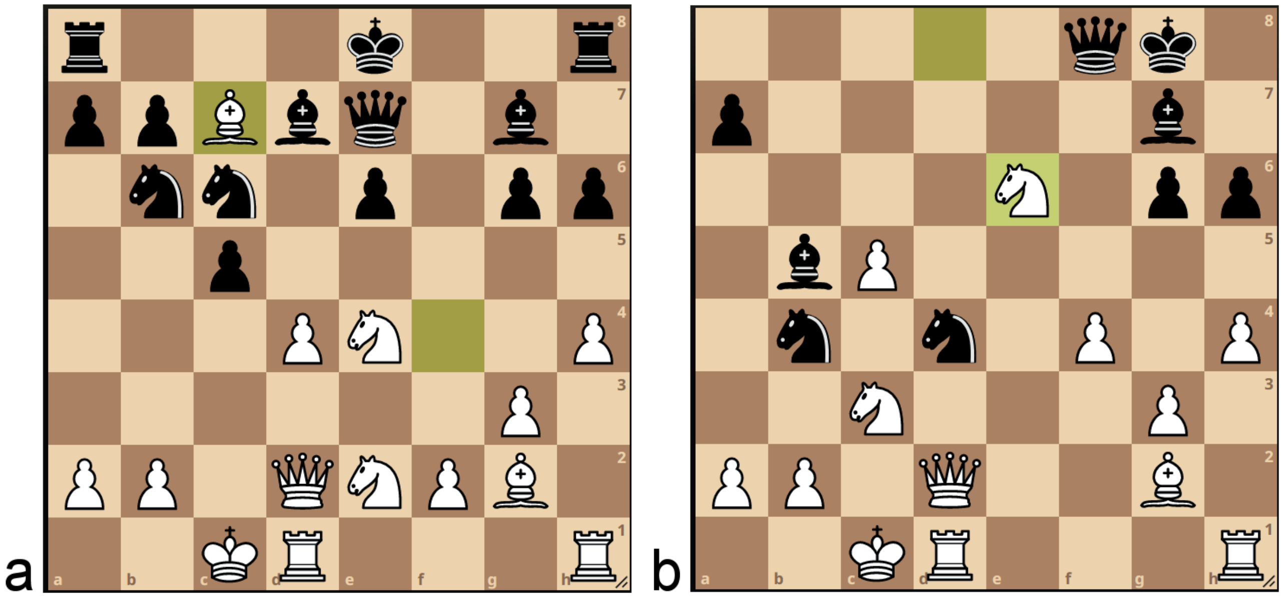

Figure 9. Śliwa vs. Bronstein, Gotha, 1957, 1 – 0. In the position shown in (a), White has just taken the pawn on c7, expecting that this would prevent Black from castling on either side, but Black, in the spirit of Petrov's immortal, castled anyway, giving up the exchange after 15…0-0 16.Bd6 Qf7 17.Bxf8 and also neglecting to take the free pawn on d4, giving away its own central pawn instead after 17…Rxf8 18.dxc5. Five moves later Black would sacrifice his second rook and then the queen: once by playing 24…Bd3 in the position shown in (b), the second time with 25. Bd5 Qf5, and the third time with 26. Nxd4+ Qxd5. In none of the scenarios can the black queen be captured or else White loses after 25.Nxf8 Nxa2 26.Nxa2 Nb3#, 26.Nxd4 Qxd5 27.Nxd5 Nxa2#, or 27.Nxd5 Nxa2#, respectively. White did not fall for any of the queen sacrifices, having correctly assessed that the value of either of the two white knights, which dominated the game both offensively and defensively, was greater than that of the black queen. The game continued with 27.Nc2 Bxc3 28.bxc3 Qxa2 29.cxb4, at which point Black resigned.

WEEK 9, YEAR 1957: ŚLIWA VS. BRONSTEIN

"Exhaustive search for move selection rules chess out as a game of intelligence"[58], David Bronstein noted once, but this despondent remark has a brighter side, for it can be considered a gateway to Bronstein's lifelong consideration of chess as a game that is halfway between art and literature[59]. It can also explain his perpetual quest to accomplish beauty in over-the-board contests instead of focusing on pure exhibitions of intelligence and petty strivings for victory. Besides, when expressions get suppressed, dreams abound, not only in chess and science, but in every art and every walk of life. And if there ever was an epitome of a daydreamer among the world's top chess players, then it must be David Bronstein, himself, who once spent 40 minutes deliberating over his first move as White and on another occasion was so deeply immersed in his thoughts that he thought that the game was over and that he was analyzing it at home. The blunder he made in that instant, touching the king instead of the knight in Game 6 of the world championship match against Botvinnik in Moscow in 1951 and having to play 57…Kc2 instead of 57…Ne6+, in fact, cost him the world champion title. As a result, no chess player in the 20^{th} century except him and Carl Schlechter ended up being so close to becoming the world champions, yet they both squandered their opportunities through staggering blunders[60,61]. Still, what Bronstein's career in chess can illustrate is that losers can often inspire more than the winners. In a way, it is a testimony to the witty truism: "Winning is for losers"[62]. Therefore, his dreamy and daring style of play, where imagination was valued more than the achievement of winning, can provide a definite source of inspiration for students in search of creative outlooks and ideas. Bronstein's throwing himself into a lost position already by move 13 of the game against the Polish chess master, Bogdan Śliwa in 1957 and then complicating the position via a number of sacrifices topped with a triple queen sacrifice (Fig.9), in fact, earned this game the epithet of an immortal losing game. Unfortunately for Bronstein, his opponent played prudently and correctly, accepting only those sacrifices that were acceptable. Nonetheless, the epithet that the game earned since it was played suggests that losing need not be an obstacle for delivering beauty to the world of science, or world in general. As Bronstein, himself, pointed out in one of his two most popular chess books to date, the one portraying the 1953 Zurich chess tournament, "How sad it can be to end up minus both piece and attack, to sit and wonder: 'How did all this happen? Where did I go wrong?'… but at the very end, fortune favored the brave"[63].

Coincidentally or not, a year before this game was played, in 1956, the British physicist and mathematician, Paul Dirac formulated the principle according to which having beauty in one's equations is more important than having them match the reality[64]. To this day, the explication of this principle, coming from the least likely of sources, namely the realm of elementary particle physics, where semantic connections were thought to be made based on the rules of math and logic alone, represents a seismic shift in the way natural sciences could and should be perceived if our goal is not the engagement in the reiteration of the trite old paradigms, but the production of revolutionary fundamental novelties. Yet, what must be noticed is that from today's entrepreneurial climate of modern science, worldviews such as those of Dirac and Bronstein have been ruthlessly expelled and kept at bay. Neither do scientists any longer look for ethereal beauties inside their equations and scientific models nor are the merits of quixotic dreaminess for rational conceptualization recognized in educational or research institutions of the day. Prosaic pragmatics and coldblooded careerism have instead suppressed and put into chains any romantic aspirations to turn a game of chess, a scientific paper or any other intellectual project into a piece of art, notwithstanding the cost.

WEEK 10, YEAR 1960: TAL VS. BOTVINNIK

After World War II and the era of Alekhine's reign as the world champion were over, in 1945 and 1947, respectively, most developments in chess playstyle revolved around static positional principles. The dynamic unsettling of the equilibrium, by comparison, was rarely employed in a systematic manner. This solid and highly principled style of play is usually tied to Mikhail Botvinnik, who is considered the patriarch of the Soviet chess of school, which ended up dominating the world of chess for over half a century after the death of Alekhine. From this post-World War II period, a similar era of sanity emerged within the scientific community, the toll of which came in the form of a stall and dwindle of revolutionarily profound, conceptual innovations, the trend that is actual today just as it was back then. The major opponent of Botvinnik's school came to prominence from the same country in the late 1950s, representing to this day the most rebellious of all chess players: Misha Tal. The clash between them for the world champion title was analogous to that between Edison and Tesla, the former of whom represents the modern principal investigator as a capitalist, an autocrat and an exploiter of young graduate and postdoctoral talents through his own talent for entrepreneurship and fundraising, and the latter of whom represents a solitary scientist and a creative genius, albeit unable to relate to the mundanities of the social reality. As a reminder, one essential message handed to us by Tesla's legacy is that if he managed to be guided by mystical, authentically romantic visions in his work on invention of high-tech appliances, then virtually every other field of science, from the least to the most theoretical or practical, can and should feed on ideas that border art, philosophy and theology, just the way it was done in ancient Greece, where philosophical treatises, theatrical plays and scientific discussions formed an indissoluble concoction. Yet, this romantic and renaissance attitude has been largely abolished from the modern science by the lineage of entrepreneurial mindsets whose exploitative approach is traceable to that of Edison. To them, materialistic drives and diligence sprinkled with a bit of the wit of the intellect is all that counts, whereas any digressions into lyricism or metaphysics are perceived as foreign and need be averted at all costs.

Hence, as we see, the encounter of the principled patriarch of the game, Mikhail Botvinnik, and the lone pirate and the gambler, Misha Tal, was an encounter of values of far greater significance that those pertaining to mere wood-pushing on the chessboard. While the former founded an entire school and a system of chess, leaving an immense and lasting practical impact on the game, the latter was an ever present source of inspiration for the artists, and who among the two the students in arts or sciences would pick as their favorite in this match is always curious to see: the suit and the tie and the airs of grandiosity and the lushes of a managerial lifestyle feeding off of capitalist exploitation that Mr. Correct represented or the life of a "Napoleon in rags"[65], a renegade and perpetual outlaw that Mr. Incorrect was. Their first world championship match, in 1960, was won by Tal and the second one, a year later, by Botvinnik, meaning that Tal, like Vasya Smyslov earlier, only shortly interrupted the decade and a half long residence of Botvinnik on the world champion throne. In any case, given the poetic peculiarities of his style, Tal's accomplishment is as fantastic as the scientific and technological

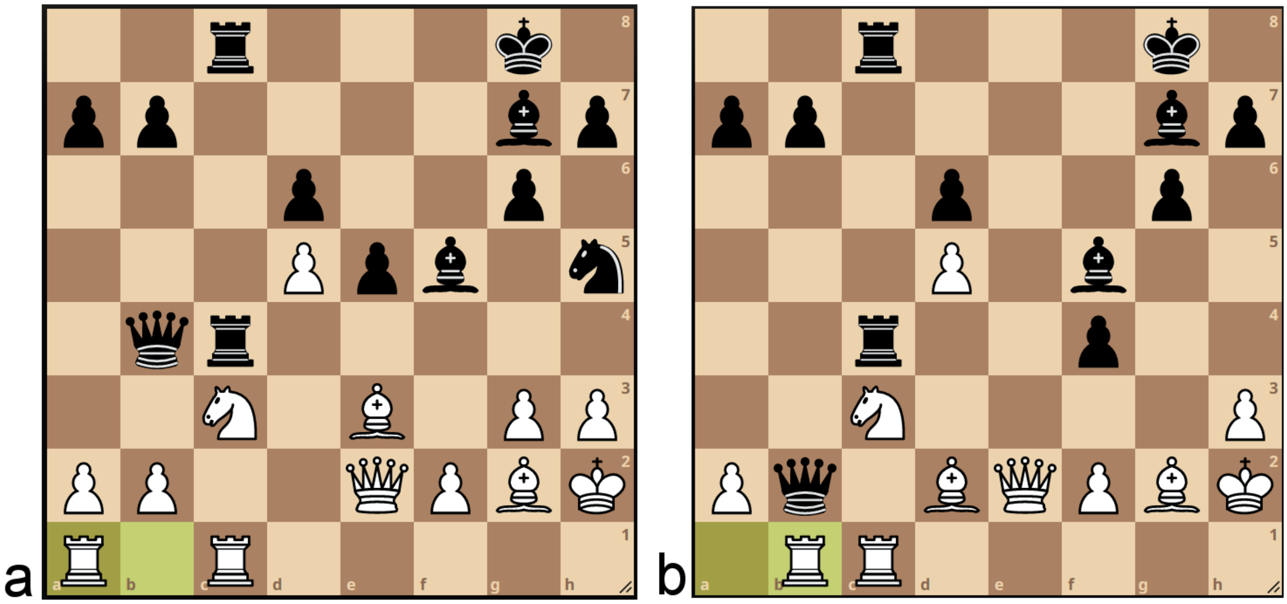

Figure 10. Botvinnik – Tal, World Championship Match, Game 6, Moscow, 1960, 0 – 1. In the position shown in (a), Tal intuitively sacrificed the knight with 21…Nf4, which was followed by 22.gxf4 exf4 23.Bd2 Qxb2 24.Rab1. At that point, the position shown in (b) was reached, in which Tal sacrificed the f pawn by playing 24…f3, thus continuing to create dynamic complications characteristic for his style and prompting White to make the key mistake of the game by taking the queen on b2 with 25.Rxb2.

feat of sending the first man to space, which coincidentally happened a year after Tal upset the chess world and became its king. The sacrificial and speculative style of Misha Tal, a self-proclaimed chess gambler, was curbed in these memorable matches, but a moment from Game 6 of the 1960 match nicely illustrates its essence (Fig.10). Tal's oeuvre, of course, contains hundreds of games with more ecstatic and mind-boggling sacrifices, but the one from this example stands out because of its historical importance and for the famous uproar it caused among the audience both during the game, when cheering in the hall started to get so loud that the players had to move to the backstage to be able to play, and also after the game, when the excitement of the crowd spilled out to the streets of Moscow.

The sacrificial style of Misha Tal can be an endless source of inspiration for the explorers of creative ways of impression and expression in virtually every type of art or science. After all, to break the rules and habits of "good" behavior, which Tal carried out regularly on the chessboard, is the first step toward being enlightened by new ideas, and this is where creativity, really, begins. One experiment converging with this principle was being conceived during Tal's short reign at the summit of the world; it is nowadays known as the Milgram experiment. According to the findings of Milgram's study from 1961[66], people faced with the choice of either following the moral obligation not to hurt other people or obeying the authority overwhelmingly opt for the latter, even when this entails the infliction of staggering levels of pain onto fellow humans. Conversely, if our goal in life is to be benevolent to other people, then we have no other choice but to disobey the authority, whichever the form it takes – administrative, physical, abstract. After all, exhibitions of creativity in sciences are preconditioned by the ability to recognize and the freedom to pinpoint the deficiencies in the existing fabric of knowledge, and from there on propose the means of amending them, which is a stance that sooner or later brings one at odds with the powers that be. Tal's style of play, wild and anarchic, free like a bird, epitomizes very well these clashes with the authority, without which, as we see, no human hearts could be touched and hardly anything poetic and beautiful could be brought to life.

WEEK 11, YEAR 1972: FISCHER VS. SPASSKY

Bobby Fischer was active in professional chess since the mid-1950s. However, as the 1970s began, something strange happened; it was as if a source of inexhaustibly creative streams were unleashed in his head. He suddenly managed to open a backdoor to the crypts of human consciousness, showing how immense the powers latent in it are and how everybody on the other side of the board is vulnerable and can be crushed into pieces with a right frame of mind. Many of Fischer's games were similar to watching a boxer deliver punch after punch, with moves naturally flowing from one into another, each posing a threat and then the threats multiplying until the opponent's position crumbles like a deck of cards. One example of this is Game 6 of the world championship match he played against Spassky in Reykjavik in 1972 (Fig.11). In this memorable game, Fischer did not only decide to play a closed game for only the third time in his career, surprising everyone in the audience, but he also opted for the Tartakower variation of the queen's gambit declined, in which his opponent had never lost a game. That Fischer in those days unlocked a secret bolt in his mind, from which the streams of a mountainous prowess began to gush out, is evident from the fact that no player before or after him could win 6-0 and 6-0 in two rounds of the Candidates tournament, as he did against Taimanov and Larsen, and score 20 wins in 20 straight games at the Interzonal and Candidates level, playing all the while all alone, with no seconds, against opponents who worked with whole teams of trainers and seconds. Neither did any player before or after him begin the world championship match with a deliberate blunder, *i.e.*, 29…Bxh2 in Game 1, and then not showing up at all for Game 2, thus starting with a 0-2 score, but only to win 5 out of the next 8 games and eventually get crowned as a new world champion. Neither did any player before or after him concede the world champion title without a match, but such are the paths of extraordinarily creative personalities: strange, stranger, strangest, irrational, illogical, impossible to understand, but with something unspeakably sensible peeking from their hearts.

To this day, Bobby Fischer represents a living proof that the creative brain is an iceberg, only the tip of which is usually prominent. Fischer's display of this extraordinary mental power, interestingly, coincided with the decade of unusually inhumane experimentation in psychology in the United States, predating the Belmont report of 1979 issued by the American Psychological Association. Further, on the same year when Fischer became the world champion, the first experiments on quantum entanglement, aka "spooky action at distance", were conducted at UC Berkeley[67], while the legitimate research experiment on parapsychology aka the Philip experiment was performed by a research group associated with the University of Toronto. For better or worse, the global fascination with mindreading, with clairvoyance, with tuning into collective consciousness and with other forms of action at distance has toned down since those days, yet all these phenomena remain bottomless wells of inspiration for the seekers of stupendous creative powers inside them. As for sciences, Fischer's fantastic skills can inspire the scientists to come to terms with the belief that solutions to even the most complex puzzles in science and life can be glimpsed in the blink of an eye, if they only be stormed by intuition and reason walking hand-in-hand, in Bobby Fischer style.

However, nearly as soon as he became the champion, he, the king, walked away from the throne and into shadows, never again to play an official chess game under the auspices of FIDE. In 1975, the world champion title would be handed over to Anatoly Karpov and this would mark the precedential moment in the 20th century, where politics would interfere with the best play on the board. In 2023, as this paper was being written, the longest reigning world chess champion in the 21st century, Magnus Carlsen, would become the first world champion after Fischer to refuse to defend the title, yet unlike after Alekhine's untimely death as the world champion in 1946, after Fischer's own declining to defend the title in 1975 or after the unification of two chess federations in 2006, when tournaments were held to decide the new champion, a strange system was implemented, forcing Ian Nepomniachtchi, who decisively won the Candidates tournament, to play a world championship match against the tournament runner-up, a match he would eventually lose. All this suggests, between the lines, that politics continues to stream like an undercurrent in every human profession and discipline, guiding every decision-making process and power distribution protocols therein. Party politics, geopolitics and micropolitics have always influenced segregation in chess and in any other social domain, yet there is the impression that the long lineage of the crude political influence in chess, rising with the tide of the Cold War and taking tolls on the careers of the likes of David Bronstein or Viktor Korchnoi by the Soviet communist propaganda, culminated in the early 1990s, first with Fischer's criminal prosecution for playing an unofficial world championship rematch against Spassky in 1992 in my native country, Yugoslavia, and then with the splitting of the Professional Chess Association (PCA) from FIDE in 1993, at which point the question of who the best player in the world became a blatantly political one. In chess, however, as in individual sports in general, there is still an over-the-board contest, some may say, and there is only so much politics can do to interfere with the fundamental skills of the players, whereas in science, there are none of such face-to-face encounters to determine the better performer, meaning that politics can be and has been a far greater determinant of

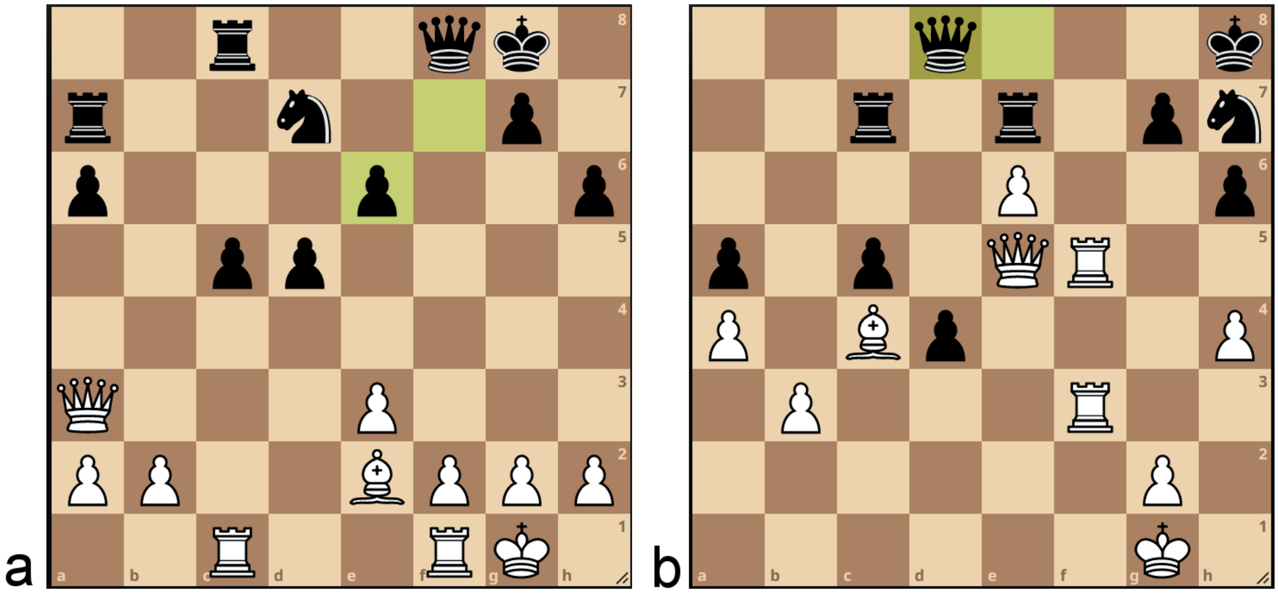

Figure 11. Fischer vs. Spassky, Game 6, World Championship Match, Reykjavik, 1972, 1 – 0. Position on the board (a) before Fischer played 20.e4, sacrificing the central pawn to open up the a2-g7 diagonal for the light-squared bishop and undermining Black's seemingly sturdy pawn structure in the center. The move was followed by 20…d4 21.f4, with which Fischer started the attack on the kingside, as black pawns would soon be immobilized on the queenside by the bishop stationed on c4. After ten moves, Black was reduced to a completely passive position shown in (b) and the aimless wondering of the queen from d8 to e8 and back a couple of times, at which point White launched the final assault by moving the bishop to d3, performing an exchange sacrifice and then returning the bishop quietly to c4, where it would stay until the end of the game: 36.Bd3 Qe8 37.Qe4 Nf6 38.Rxf6 gxf6 39.Rxf6 Kg8 40.Bc4 Kh8 41.Qf4.

the ascents and descents in careers in science than the objective skill, affecting particularly adversely the prodigious and heterodox individuals of the likes of Bobby Fischer. It is in the nature of the romanticists, everywhere and at all times, to mistrust politics, yet it has been nothing short of ironic that the fosterage of chess as a competition, where over-the-board contests decide who progresses to the top and who slides toward the bottom, which the romanticist equally abhors, has come up as the conventional remedy against this inflow of politics, when viewing chess as a form of art and chess players as its co-creators could have provided a much better solution. As for these clutches of politics hovering ominously over everything, one key aspect of the romantic thought is the embracement of cosmopolitanism and freeness from political prejudices, but so is the intense search for truth and for bold ways to express it. This is exactly what puts the romanticist at perpetual odds with the establishment, which, like the Grand Inquisitor[68], holds the keys to this very truth, relativist by nature, in its hands. Paralleling the intense emphasis on constructivist, psychological effects in sciences, sociologically inclined philosophers of science of the 1960s and the 1970s, including, most prominently, Thomas Kuhn, were busy pointing out the relativism of truth in science[69], specifically how what is true and what is not is predominantly determined by the degree of acceptance by the scientific community[70], a process that favors those who are skilled at bowing to the mob as opposed to the nonconformists who always find themselves at odds with it. However, rather than humanizing natural sciences, the proliferation of these relativistic attitudes has taken the energetic enthusiasm that is romanticist in essence and diluted it in the bland waters of pervasive pliancy and "anything goes"[71] attitudes.

WEEK 12, YEAR 1985: KARPOV VS. KASPAROV

The world champion title matches between Anatoly Karpov and Garry Kasparov in the 1980s were the last time two players with distinct, diametrically opposite personalities and playstyles met at the highest stage in chess, with the corresponding ability to polarize the globe. Both of them were Soviets, but while Karpov epitomized the law and order of the bureaucratic establishment, Kasparov personified the free spirit of rebels against the convention and dissidents against political

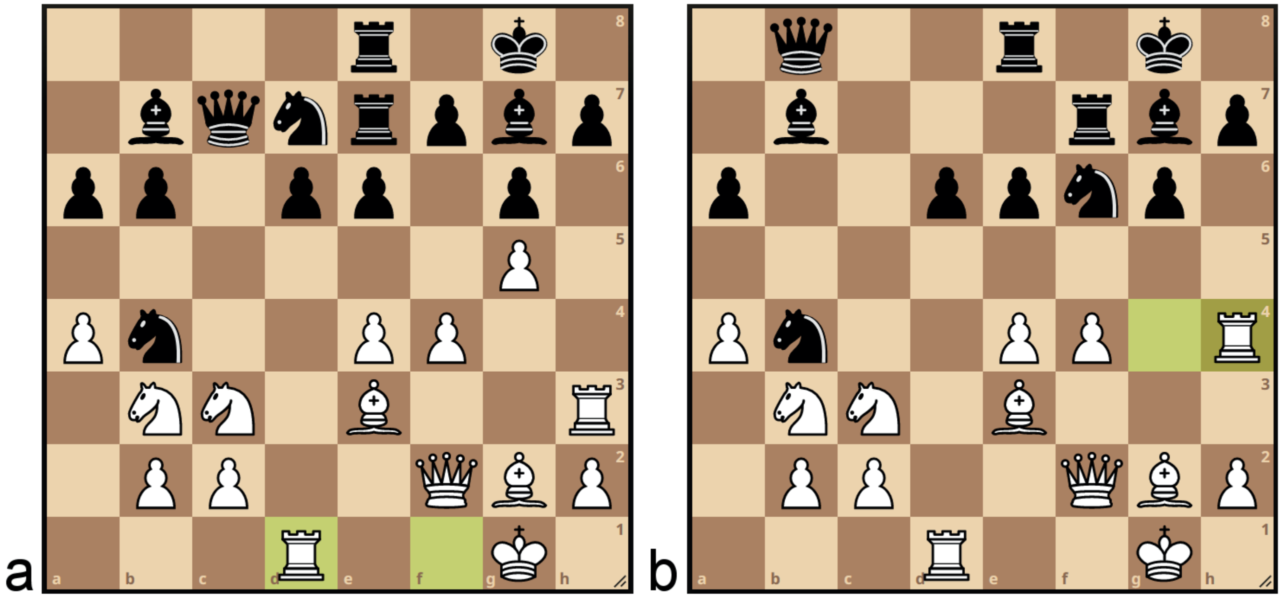

Figure 12. Karpov vs. Kasparov, Game 24, World Championship Match, Moscow, 1985, 0 – 1. Needing only to draw the game as Black to win the title of the world champion, Kasparov sacrifices one pawn after 25…f5 26.gxf6 Nxf6 (instead of more logical 26…Bxf6) (a) and then another with 31…g5 (b) to gain initiative and win the game as Black.

oppression. Their first match, played in 1984/85, having Kasparov as the contender and Karpov as the defender of the title, started unfavorably for the former, who played in his own characteristic style, aggressively and boldly, but got crushed by the system, finding himself trailing 5 to 0 in a match played up to 6 wins. At that point, Kasparov decided to soften up his approach and play more conventionally, the result of which was an endless series of draws intercepted by three wins for Kasparov. After 48 games played and the score of 5-3 in favor of Karpov, both players complained of exhaustion and the match was aborted, with the sequel being scheduled for later in the year in a different format. Kasparov, now more harnessed, started playing with more success and after 23 games played, he was in the lead by one point, meaning that if he was to at least draw the last, 24th game as Black, he would become the new world champion. And when most players would play one such game defensively and cautiously, he opted to fight the fire of Karpov's attack with the fire of his own blasting attack, sacrificing two pawns (Fig.12) and winning the game that he needed not win. Like the chemists who twisted and curled graphite at around this same time[72], all until the sheets folded into a new allotropic modification of carbon known as fullerenes or buckyballs, Kasparov twisted the minds of mediocre minions who followed the game, bent them into balls and rolled them down imaginary hills and valleys. The audacity of his approach in this last game can serve as inspiration on how to approach science, too: boldly, not bending under the pressure of the opponent or the authority, but rushing to face the lion in the most direct and daring ways possible. Although both chess players and scientists tend to lose this valiant impudence of their outlooks as they mature, a room for it always remains in mindsets determined to come up with stunningly creative ideas, regardless of one's age and discipline. In other words, dissentience and creativity have been but two sides of the same coin jingling in the holey pockets of romanticists all the world over[73].

With Kasparov's win in this game, chess romanticism popped its head higher than usual from the subterranean canals to which it had been confined. This is how the discovery of the wreck of *Titanic* somewhere in the Atlantic Ocean on September 1, 1985, only two days before the match that would decide the new world champion began, can be an analogy that extends its semantic rays of meaning to multiple levels, including those within the multiverses of chess and science. Albeit discovered for just a little while, though, this romanticism was, likewise, a wreck and was to be left where it had been found, in the dark depths of the ocean, surrounded by mermaids and anemones. Science, after all, is still more interested in the surface of things and continues to neglect these dark philosophical depths where romantic ideals slumber to this day. Yet, to grow independent and then shun the roots of philosophy from which it sprang to life cannot do anything good to science. Like a soul haunted by the bad karma, science as such may be destined to roam godlessly, like a headless fly, in hope that, someday, it gets reunited with these forgotten roots and reach out to philosophy and art and theology so intimately that everything in sciences from then on becomes a renaissance concoction of disparate points of view. To make this possible, a lot of hard work, a lot of inspiration and a lot of courage, like that exhibited by Kasparov here, is needed. One thing is certain, though: chess, the game that is a form of fusion of science and art, can inspire us and show us the way.

WEEK 13, YEAR 1991: USKOKOVIĆ, V. VS. COLOSSUS CHESS 4.0

The early 1990s, when I, a teenager at the time, nurtured the dreams of becoming a professional chess player, was the first time computers reached the level of play comparable to those of masters or candidate masters. As an expert player and computer buff, logically, chess programs were my regular partners and I produced numerous exciting games from that period[74]. Many of them can be a proper illustration of how whenever romanticism is dying on the big stage, it is being reborn in darker corners, which need be sought with great patience and insight. Although the games of choice from the years of my daily clashes with the computer may vary depending on the interest of the class or the inspiration of the moment, the game described here is one of the universally interesting ones because it was my first win against a computer engine, which took a little less than 100 moves to reach the checkmate. It started off with opposite side castling in the Panov transfer variation of the Scandinavian defense (Fig.13a), but its key point was the ambitious, albeit rather dubious and seemingly unsound positional sacrifice of a knight in the middlegame (Fig.13b). Although at the very first sight 23. Nxe5 seems completely irrational compared to the logical 23.Nxd4, today, with the use of supercomputers, we know that this move was nowhere as ridiculous as it may seem. Firstly, Nxd4 is met with …Bxd1 in every variation and Black would stand better, whereas meeting 23.Nxe5 with 23…Bxd1 would give advantage to White according to Stockfish after the white queen takes on d5. The move 23.Nxe5, in fact, represents Stockfish's second best choice in the deepest mode, right after 23.Nxd4 and before 23.Re1. In all these circumstances, Black, that is, the engine, preserves the advantage, but the strange and counterintuitive 23.Nxe5 allows White to muddle up the position and give away the knight for doubled rooks along the now open e file, a better positioned light-squared bishop and a connected passer in the center. Refusing the sacrifice does not favor Black, as after 23…Ne2, 24.Qa5 Nf4, for example, Stockfish gives a 0.0 evaluation. In fact, the only move that preserves the advantage for Black is accepting the knight sacrifice, the cost of which was slightly improved positioning of white pieces after the moves played in the game: 23. Nxe5 Qxe5 24. Re1 Qf4 25. Bd5+ Kh8 26. Rhe3 Nc6 27. Be4. The correct plan for Black in this position is to engage in defensive play that would prevent the marching of the connected white e pawn toward promotion, but Black, instead, started chomping on one white pawn after another, which were becoming increasingly poisonous, first the f2, then the h4, and then, the most forbidden of them all, the c4. Taking on c4, in fact, turned the tables around and gave White a solid advantage because after 32…Qxc4 33.Rc3 (Fig.13c), the black bishop better be given away or else the pawn would promote to queen. Namely, if Black tries to defend the bishop with 33…Qg4, then 34.Rxc8 Rxc8 35.Bf5 wins for White and if Black defends it with 33…Qh4, then 34.Rxc8 Rxc8 35.d7 follows and Black cannot stop the promotion. In the game, Black deemed it smartest to drop the bishop, which turned the game into a queen versus rook and knight endgame, of a similar type as that which Magnus Carlsen won against Ian Nepomniachtchi in the rollercoaster of Game 6 of the world championship match in 2021, albeit from the opposite, rook-and-knight side of the board. Here, White managed to once again allure Black to take all of the remaining white pawns, but at a dire cost, namely that of losing the coordination between the rook and the knight, which we know from the aforementioned game between Carlsen and Nepomniachtchi to be of crucial importance in this type of endgame. Here, White found a move that is decorated with an exclamation mark by Stockfish in 2023: 50.Qh2+ (Fig.13d), which led to the overtaking of the initiative and a win against Colossus Chess 4.0, a computer software programmed by Martin Bryant in 1985, containing 3,000 opening positions and the rating reaching up to nearly 2000 on the USCF scale on the Commodore 64 8-bit platform. Games like this one, played in a children's room against a computer, in the years when chess software on home computers for the first time started being interesting to play against for experts, may be obscure in the global context and may even abound with a whole lot of inaccuracies and errors, but can also be a greater joy for students to relate to and learn from than many of the superbly precise technical grinds that are common at the grandmaster level. The same goes for homemade research, carried out in more

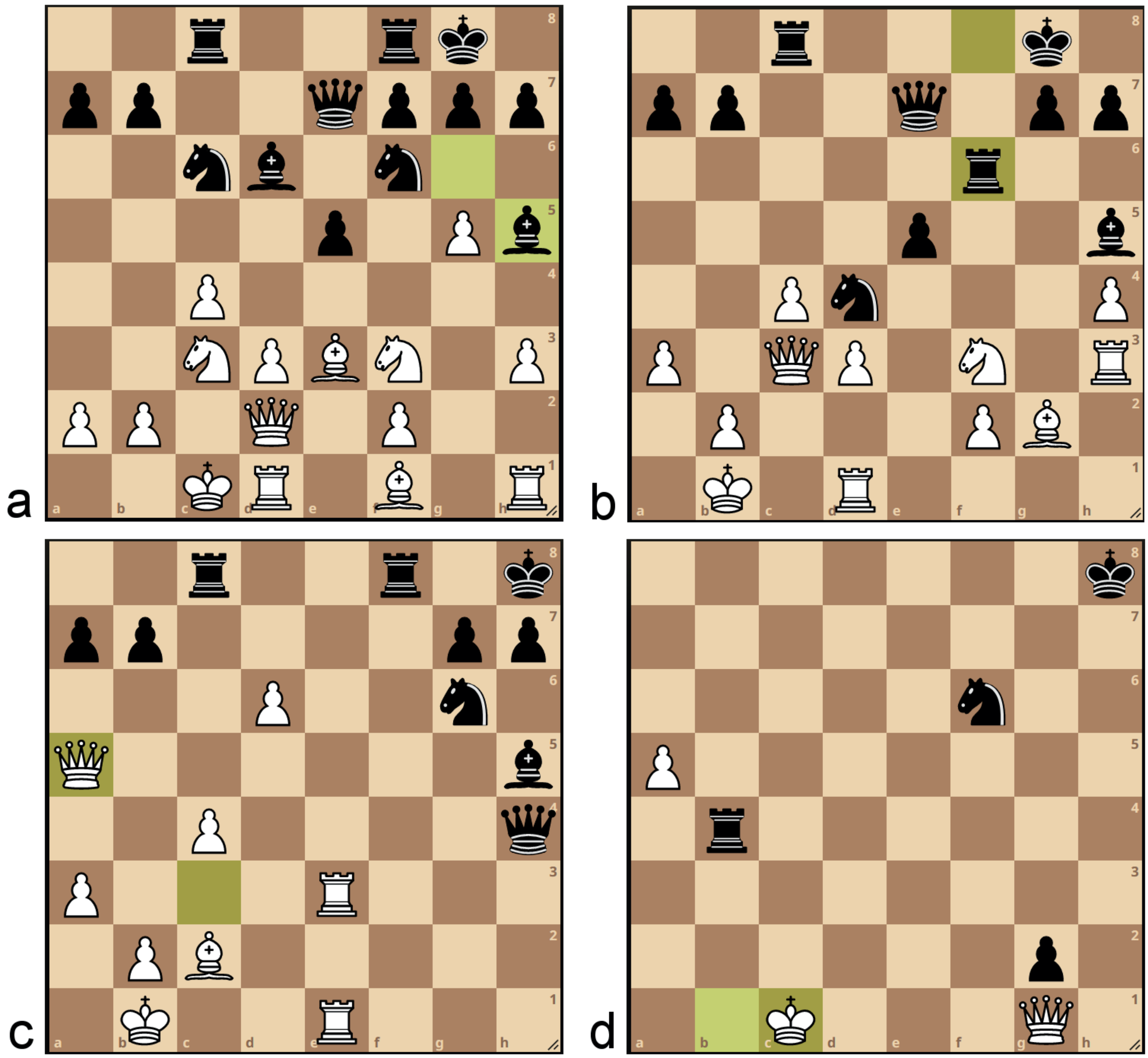

Figure 13. Usković, V. vs. Colossus Chess 4.0, Belgrade, 1991, 1 – 0. (a) In this position, White chooses to develop cautiously with 14.Bg2 instead of blasting the g file open with stronger 14.gxf6. (b) Position on the board before the key dynamic move of the game, 23.Nxe5, which appears counterintuitive, but presents the second best choice by Stockfish 15.1. (c) In this position, Colossus plays 32…Qxc4 and chomps on the third pawn in a row, but blunders the bishop after 33.Rc3 and loses the advantage. (d) Position on the board before Black played 49…Ra4 and White found the winning move, 50.Qh2+, which spiked the Stockfish evaluation from 0.0 to +4.0. PGN: 1. e4 d5 2. exd5 Nf6 3. c4 c6 4. dxc6 Nxc6 5. d3 e5 6. Nc3 Bf5 7. Nf3 Bc5 8. Be3 Bd6 9. Qd2 O-O 10. O-O-O Rc8 11. h3 Qe7 12. g4 Bg6 13. g5 Bh5 14. Bg2 Nd7 15. h4 Bb4 16. a3 Nc5 17. Kb1 Nb3 18. Qc2 Bxc3 19. Qxc3 Ncd4 20. Bxd4 Nxd4 21. Rh3 f6 22. gxf6 Rxf6 23. Nxe5 Qxe5 24. Re1 Qf4 25. Bd5+ Kh8 26. Rhe3 Nc6 27. Be4 Qxf2 28. d4 Qxh4 29. d5 Ne7 30. Bc2 Ng6 31. d6 Rff8 32. Qa5 Qxc4 33. Rc3 Qd4 34. Rxc8 Rxc8 35. Qxh5 Qd2 36. Re2 Qxd6 37. Rh2 Nf8 38. Bxh7 Qxh2 39. Qxh2 Nxh7 40. Qg1 b6 41. Qh1 Rg8 42. Qb7 g5 43. Qxa7 g4 44. Qxb6 g3 45. Qg1 g2 46. b4 Nf6 47. a4 Rg4 48. a5 Rxb4+ 49. Kc1 Ra4 50. Qh2+ Nh7 51. Qe5+ Kg8 52. Qd5+ Kf8 53. Qxg2 Rxa5 54. Qf3+ Ke7 55. Qe4+ Kd6 56. Qxh7 Rd5 57. Kc2 Ke5 58. Kc3 Rc5+ 59. Kb4 Rd5 60. Qh8+ Ke4 61. Qh1+ Ke5 62. Qh2+ Kf5 63. Qh3+ Ke5 64. Qe3+ Kf6 65. Kc4 Rf5 66. Kd4 Ra5 67. Qf4+ Ke6 68. Qh6+ Kd7 69. Qg7+ Ke6 70. Qg6+ Ke7 71. Qc6 Rg5 72. Qe4+ Kf6 73. Qf4+ Rf5 74. Qd6+ Kg7 75. Ke4 Rf1 76. Qd4+ Kf7 77. Qd5+ Kf6 78. Qe5+ Kf7 79. Qh5+ Kf8 80. Ke5 Re1+ 81. Kd6 Rg1 82. Qf5+ Kg8 83. Ke7 Rg7+ 84. Ke6 Ra7 85. Qg4+ Rg7 86. Qd4 Rg6+ 87. Ke7 Rg7+ 88. Kf6 Kh7 89. Qh4+ Kg8 90. Qh5 Rg1 91. Qd5+ Kh7 92. Qe4+ Kg8 93. Qa8+ Kh7 94. Qa7+ Kg8 95. Qxg1+ Kf8 96. Qg7+ Ke8 97. Qe7#

intimate settings than those of the mainstream labs of academic institutions and industrial sites: they connect to the young people, according to my experience, much better than the formally conducted research, alongside transmitting the noble idea that everyone at any time can be a creator and conductor of experiments that can change the world. At this spot, an excursion is made to the aforementioned research from my personal oeuvre in the early 2020s, when the excommunication from academia for political reasons, the loss of employment and the closure of an institutional lab inspired me to involve myself and children in research carried out in home bedrooms[75], garages[76], kitchens[77],[78], backyards[79], lakes[80], parks[81], pools[82] and playgrounds[83],[84], arriving at far more stimulating findings and presenting them in far more inspirational ways than ever before.

At the time this game was played, in May 1991, a bigger conflict was looming over my world than that taking place on the chessboard before me. It was the Yugoslav civil war and the breakup of Yugoslavia, which would begin a month later with the secession of the former Yugoslav republic of Slovenia. In the couple of years that followed, my home country rapidly drifted into international isolation and destitution like that unseen in Europe since World War II, and so the dream of competing on the big stage as a professional chess player, naturally, deflated. Simultaneously, a country that once organized a number of notable chess tournaments, including the last chess Olympiad before the breakup of the country, in 1990, and up to that point won most medals in these Olympiads after Soviet Union, deteriorated to a state where it could organize only events of dubious credibility, such as the Fischer vs. Spassky world championship rematch in 1992, with financial incentives trickling through illegal banking schemes. The urgency of directing intellectual efforts to skills enabling emigration from a country that rapidly sank into destructive nationalism thus became a priority and this is how chess was replaced by science from the center of my sphere of interests. Meanwhile, I could observe first-hand the desperation of scientists, such as my fathers', when aspirations to share their discoveries with the whole world were discriminatively stood in the way of[85] only because they originated from a country vilified by the international community, regardless of the fact that scientists and other intellectuals, including myself, protested loudly against the war and the warmongers and often put their lives on the line to defend people of all nations who were endangered by it. Be that as it may, this is how a dream of a career in chess was cut short before it even took off, but a lesson was learned. It was a lesson on how circumstances can obstruct people's aspirations, which is a humbling insight that should always stand in the way of thoughtless judgments. In other words, knowing how profoundly the existential history can affect the paths one walks on in the present and the horizons toward one drifts in the future raises the awareness of how everyone's effort is appreciable. This universal appreciation is the stance of first and foremost importance that academic instructors and mentors ought to be equipped with in the times of the ongoing epidemic of oppressive arrogance and prickly egos that proliferate abundantly across the academic multiverse.

WEEK 14, YEAR 2000: KASPAROV VS. KRAMNIK

The end to the era of Kasparov's dynamism came in the classical world championship match he lost to Vladimir Kramnik in 2000. The most notable detail about this match was how Kasparov's usually effective attack bumped into the Berlin Wall variation of the Ruy-Lopez that Kramnik employed as Black. In the example shown in Fig.14 from Game 3 of the match, Kasparov as White controlled both open files with his rooks, yet Kramnik as Black left no squares for him to penetrate Black's position and disrupt it[86]. This rather dry and defensive Berlin Wall variation dulled and neutralized one of the most imaginative and dynamic attackers in chess history. After bumping his head against the Berlin Wall in Game 1, Kasparov would lose patience and blunder with 39…Ke7 in Game 2 and then fall into an opening trap in the Nimzo-Indian defense in Game 10, thus losing the match and conceding his title. Since then, chess analysts have frequently observed that with Kasparov's defeat in this match, the chess world lost both of the players[87], as neither of the two were the same again: Kasparov's style lost its invincible flair and attacking creativity, while Kramnik's youthful fervor, boldness[88] and drive settled in a state of stale statics and infectious indifference, the occasional ventures into more dynamic territories notwithstanding, as in the final game of the PCA world championship match against Leko in 2004. But what the world did gain was the Berlin Wall defense, which is employed by players in search of simplification and lackluster draws intensely to this day. Symbolically, in other words, the personality was lost on both sides of the board, while the wall was raised, which very nicely sums the direction toward which science was moving at the turn of the millennium and the global entrance to the digital age. This walling of the people in an increasingly isolated and alienating world has since been a trend that swept the planet across many other social domains, including the scientific. As for the feverishly awaited turn of the millennium, neither did it end up being a remarkable time for celebration of newness and the enthusiastic search for unthinkably inventive conceptual novelties. Rather, it turned into a time of global Y2K anxieties, the tick-tock of the Radiohead clock, and complacency of the intellectuals about the neoliberal economies that have now conquered every corner of the globe, creating grave repercussions on mental health, ecology and human intelligence that will be felt by many future generations on Earth. Scientists, in the wake of this raising of a Berlin Wall, have raised similar walls of protection around their personalities and their professions. Not only can academia at every one of its levels be considered a wall[89], but the western civilization as well, including the people, fortressed by a guard after guard and a façade over façade, can be considered as walls, big or small. And if science, specifically, is a wall, who can help us raze it? The help would come from an unexpected source, as we shall see, from the partner in the shadow played with by a child in his spare time, away from the limelight, for the sole love of the game.

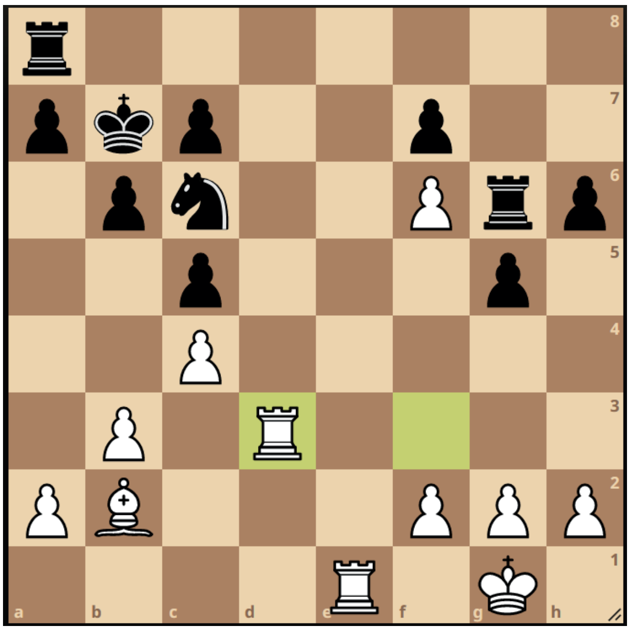

Figure 14. Kasparov vs. Kramnik, Game 3, World Championship Match, London, 2000, ½ - ½. Position on the board after 24.Rd3. White pieces cover most open squares whilst their black counterparts mostly stare at their own, yet White, somehow, has no opportunity to infiltrate Black's camp.

WEEK 15, YEAR 2007: CARLSEN VS. MOROZOVICH

As the new millennium commenced and as childlike expectations that something magical would happen deflated like a balloon and gave in to the new millennium depression[90], the state of affairs in chess and science alike reflected this sentiment. As for chess, the inauguration of Kramnik's defensive, rope-a-dope style in place of Kasparov's contagious dynamism at the top of the world, still split to two federations due to political reasons, was also a win for that long lineage of styles stretching from Capablanca to Botvinnik to Petrosian to Karpov and a defeat for Alekhine and Tal and all those who preserved the seeds of the romantic spirit in their playstyles. Although Deep Blue did win the match against Kasparov in 1997, engines at the time were still playing at an equal footing with the grandmasters and their major weapon was short-term tactics; their weakness, the broad, long-term positional thought. In other words, the computer style at the time was nothing to envy and there was little holistic foresight in it and, thus, very little aesthetics, and that same demerit appeared to have started to plague the human chess as well. Interviewed in 2003, David Bronstein, for example, condemned chess games played by Kramnik and Kasparov against chess engines because they were "not for creativity, but for a grueling match in which there is no art at all"[91]. In parallel, in natural sciences, the trend of diminishing the drive for engaging in quests for groundbreaking novelties in models, methods and modes of expression continued. Like in the chess world, any holistic tendencies to expand the scientific thought and have it enter and merge with the realms of arts or philosophy began to be looked down upon like never before in history. In the absence of these transdisciplinary inclinations, the narrowing of scientific thought led science and all things creative and imaginative in it into a state of mere craftsmanship, as the timid mindsets who had entered the profession for every other cushy satisfaction than to strike up the revolution began to bourgeon.

One aspect of human play that became a prerequisite for world-class achievements in this period was the universality of style in terms of the readiness to play both tactical and positional chess depending on the circumstances or the opponent, while constantly expanding the opening repertoire and preserving the impeccable endgame technique. The dichotomy between positional play and tactical play, so often invoked in the past to describe the playstyle of grandmasters, thus became meaningless. Naturally, at the same time, although engaging in a positional thought process had long since been a hallmark of every even slightly successful chess player, let alone of every grandmaster, the positional style of any given player, being a plexus of a plethora of positional principles that s(he) was inclined to stick to, continued to be unique to him/her. For example, Karpov and Kramnik are often

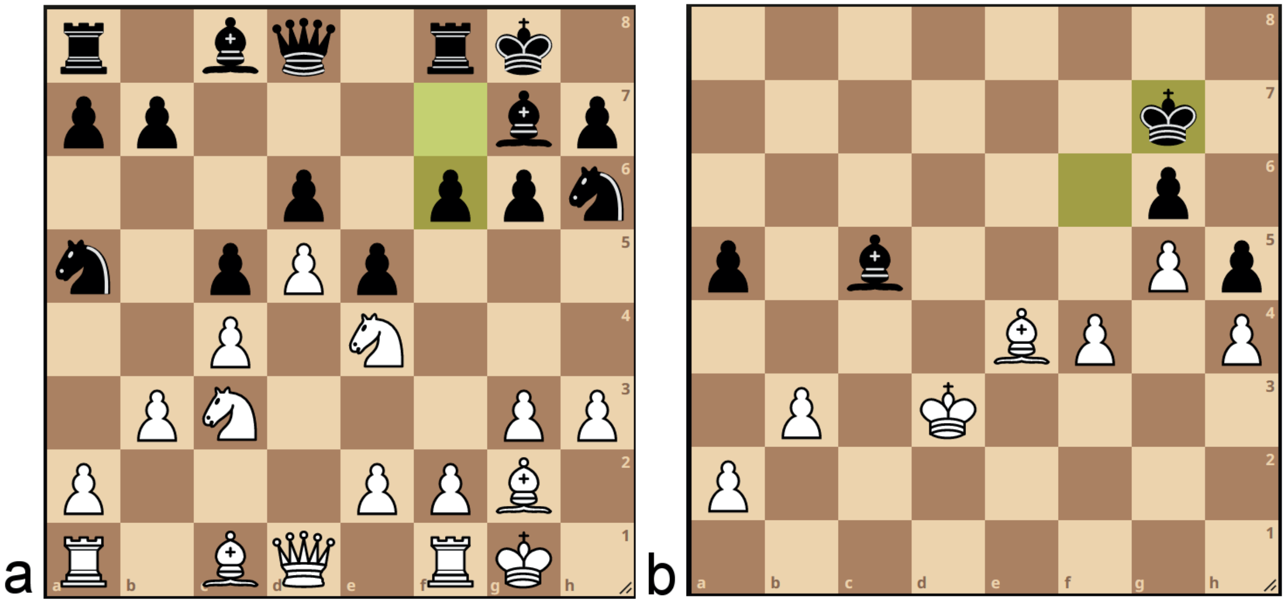

Figure 15: Carlsen vs. Morozovich, Morelia-Linares, 2007, 1 – 0. Carlsen gives away a central knight for an initiative with 13.Nxd6 (a) and then in the opposite-colored bishop endgame plays 53.Kc4 (b) and gives away all three of the white pawns on the kingside for the one black pawn on a5, having calculated that White is winning in every variation.

colloquially considered to be both predominantly defensive positional players, yet while the former relied primarily on prophylaxis, that is, on the prevention of any threats by the opponent before executing any of one's own, the latter was a player relying on classical principles and, as a result, gravitating around static positions, solid setups and passive lines. Hence, although both Karpov and Kramnik capitalized predominantly on their opponents' minor mistakes rather than on accomplishing some grandiose positional ideas of their own, their styles were profoundly different, even though both earned the epithets of defensive positional players. In fact, similar observations can be made in most team sports and one example that comes to mind is that of two English soccer players that have served to this day as paradigms of box-to-box play, namely Bryan Robson and Paul Scholes. However, while the former was a player who exceled in the defensive box owing to his physical strength and stamina and in the offensive box owing to his powerful and precise headers and the instinct of a striker, the former was a player who, like myself, having superior vision, solid playmaking skills, diligence when it came to defensive space coverage and fineness in both holding and defensive midfielder roles, exceled in any part of the field between the two boxes except inside them. Interestingly, with relatively poor ball control, sluggishness and low dexterity, Robson was an inferior player in these central areas of the pitch where Scholes excelled, whereas Scholes, with his poor headers and poor striker instincts as well as nil ability to take on the role of a sweeper, was an inferior player inside the two boxes, where Robson excelled. Hence, when one talks about box-to-box players, as in the case of many other midfielder roles in soccer, from *mezzale* to *metodisti*, it needs to be understood that the term may mean many, even diametrically opposite styles. The similar situation is found in chess, but also in science, where describing someone as an experimentalist, a theoretical thinker, a computational modeler, a writer or a speculator may mean little unless it is accompanied by volumes of further insights exemplifying one's scientific research style. Nevertheless, as science became increasingly multi-, inter- and trans-disciplinary around the turn of the century and the millennium, the ability to act in the role of everything at once, from being an intramural politician to being a lab manager to being a self-promoter, networker and advertiser on social platforms to being a cunning fundraiser, emerged as a factor of pivotal importance for a successful career in sciences. One tragic aspect of this expansion of talents required for success was that the scientific world in the aftermath of the arrival of the new century started to be increasingly populated by those who exceled in all these lateral aspects of the life and work of a scientist except in science *per se*, that is, by solid executives and entrepreneurs and not by inventive intellectuals, artists and creative renegades at heart.

Simultaneously, venturing deeper into the new century, hand-in-hand with computer engines, posed demands for the universality of style in order to compete at the world's highest stage. The player that was soon to become considered by many as the most skilled human player in the history of chess, Magnus Carlsen, epitomized this universal style that became imperative by the mid-2000s, and one example of his style of play from this period, but also later on, comes from a game where he took complete control of Alexander Morozovich, a player known for an attacking and risky playstyle. It used to be said that to beat an incredibly strong defender that Tigran Petrosian was, one would have to beat him three times: once in the opening, once in the middlegame, and once in the endgame. Carlsen's play in this game, at the age of 16 only, 6 years before he would become the third undisputed world chess champion in the 21st century (Table 1), exemplifies this universality, first through the knight sacrifice in the advance line of the Yugoslav variation of the king's Indian defense derived through an extensive opening preparation (Fig.15a), likely with the assistance of engines, and then through the quick transition to an endgame where the one pawn advantage would become converted to a win (Fig.15b), even when the endgame was theoretically the most drawish of them all, namely that of opposite-colored bishops. In parallel with this adoption of universality of style, where combinatorial vision, deep positional play and perfect technique all became blended into one, the culture globally descended into a postmodern apathy, where the aforementioned relativism has killed all the strivings for new ideologies and made everything seem fine, but also infinitely bleak, bland and, just, blah.

In response to this suffocation and suppression exerted by the walls closing in on one from all sides, the voice awakened, screaming and kicking and yelling all across the academic hallways, lecture halls, homerooms and labs, calling for the liberation of this domain from all these agencies of ill. Around the time the game between Carlsen and Morozovich was played, in 2007, everything I did in the realm of scientific research started being paralleled by writing books and papers whose goal was to tilt at the windmills representing the proliferative forces of the intellect that suppressed wisdom, beauty and creativity across all strata of the kingdom of science. At this place, even a blind selection of passages from the five books[92,93,94,95,96] updated continuously and in parallel from 2007 until this day is sufficient to intrigue the young thinkers and provide a source of enriching conversations.

WEEK 16, YEAR 2014: STOCKFISH 231014 VS. JONNY 6

By the time the two chess federations that split in 1993 reunited and Kramnik's reign as the world champion ended, in 2007, computers started to come to grips with calculations that led to deep understanding of the position and the corresponding positional play. This has helped them provide a key contribution to the opening theory and the early middlegame, the segment of the game where they hitherto could not apply their purely calculative powers as well as they did it in the tactical middlegame and the endgame. A most memorable instance of this engine-assisted opening preparation from this era comes from Vishy Anand's and his second, Rustam Kasimdzhanov's reviving the forgotten dynamic 14…Bb7 line in the Meran variation of the semi-Slav defense and using it to perplex Kramnik in Game 3 of the world championship match in 2008, prompting him to deliberate for a whole hour for the next four moves, which culminated in Anand's extraordinary double pawn sacrifice with 17…Rg4. Despite the decisive score of this famous encounter, death by draw due to the extensive opening preparation in these years started to loom over the chess world more intensely than it ever did since Capablanca had first predicted it, in the 1920s, when he had also proposed that the chessboard be expanded to more than 64 squares.

Meanwhile, as we could see from the preceding discussion, the romantic spirit continued to live at the top chess level, albeit subtly, pervading like an undercurrent the main stage whereon static positional chess played its act. Yet, as far as the world champions of the 20th century are concerned, this spirit found home in the positional central pawn sacrifice by Steinitz in his game against von Bardeleben (Fig.3); in the positional dynamics postulated and put into practice by Lasker and packaged into a perfect blend of static and dynamic positional play in the style of Alekhine; in Botvinnik's experimentations with the deliberate disruptions of the positional equilibrium; in Petrosian's routine exchange sacrifices of rooks for knights; in Tal's valiant sacrifices; in Fischer's uncompromisingly attacking mental attitude; and in Kasparov's specializing in giving away pawns to secure the initiative. However, in the early 2000s, the computers appeared to have impeded the development of this dynamic undercurrent toward more imaginative territories and many blame their intrinsic materialism for this[97], given that computers are programmed ultimately to calculate the material value of the pieces on the board as the pivotal decision-making factor. Any instances where engines proposed dynamic sacrifices were, in those times, met with disbelief, considering how rare they were. The first English grandmaster, Ray Keene, for example, commended Fritz's recommending 14…d4 to save Peter Leko from losing the aforementioned decisive Game 14 of the PCA world championship match to Kramnik in 2004, adding that "it's a mark of how far computer programs have advanced that Fritz makes this dynamic choice"[98], alongside observing that no human player would think of a gambit of this kind at the time. By the late 2000s, the best performing engines at the time did begin to come up with a little more frequent deep positional sacrifices of the material, as exemplified by Rybka's disregarding pawns and castling in the middlegame, via 14.Be2 Qb4+ 15.Kf1, then generously giving away more pawns in the endgame, as with 35.b4 Bxb4, in the memorable game against Deep Sjeng from 2009[99], but this was only a prelude to the fireworks of unexplainable sacrifices that the top computers would engage in a couple of years down the road.

Surprisingly, then, the rescue from this pending drowning of chess in the waters of insipid play came in the 2010s from the least likely of sources: the computer engines, themselves. What was widely deemed to be a problem turned out to be the solution, too. The matter, in a fantastic twist of the plot, spoke back to the mind and altered its course toward diviner destinations, if I be allowed here to use the language of poetry. Using this language, of course, is appropriate when we consider that in 2010s something magnificent started happening in the computer engine world. Namely, brought face to face, over a virtual chessboard, the engines started producing masterpieces out of games, one of which from 2014 is shown in Fig.16, containing numerous breathtaking maneuvers and demonstrating more romantic style of play than humans have been capable of achieving except on very rare occasions, alongside forming an amusing plot. The game, which was played without the assistance of opening books, opened with the so-called old variation of the queen's gambit accepted, where Black protects the captured pawn on c4 by playing …b5, just the way it used to be played in the romantic era, before Steinitz and Zukertort refuted it in the 1880s and showed that the c4 pawn better be given away by Black in exchange for developing and creating an isolated d4 pawn in White's camp. In the game, White undermined Black's pawn structure on the queenside with 6.a4 and 8.b3, as it is normally recommended, but then instead of the usual taking over of the initiative and space on the queenside, it let Black have it and allowed it to push the c pawn to promotion in little over 20 moves. Stockfish at first appeared indifferent about giving away its rook for Jonny's passed pawn, and only then, with a rook down, started pushing its own pawn toward promotion, before capturing both of Jonny's rooks for the pawn and enforcing its resignation. Perhaps most amazingly, throughout the entire course of the game, even when Stockfish allowed Jonny to queen a pawn and when it was materially down and its pieces did not seem as coordinated as Black's, its evaluation of the position was overwhelmingly in its favor. Other extraordinary games from this period of mid-2010s may include the explosive encounters of Houdini and Stockfish in Season 2 of the 2013 Top Chess Engine Championship (TCEC)[100] and of Stockfish and Komodo in Season 6 of the 2014 TCEC Superfinal[101], both of which contained fireworks of sparkly sacrifices. Another extraordinary game from 2014 was also played between Stockfish and Komodo, where the king whose pawns left him and made him exposed to an attack stood safer and fared better than the king completely protected by pawns[102]. In yet another game between these two engines from the same year[103], Black made an exchange sacrifice and then enforced the exchange of queens and the transition to an endgame with a worse pawn structure, which it won by squeezing the opponent into a prison and making advancements on the side where only the opponent had a passed pawn, defying a number of classical chess principles at once.

After all, if a chess game is perceived as a work of art and blunders its biggest enemies, then computer engines can produce greater works of art because of their immunity to crude mistakes, so long as they can be taught how to play beautifully. What turned out to have been the case was that computers, without even being trained on what constitutes beautiful play from the chess aesthetics angle, started to gravitate toward it in the mid-2010s, simply as the result of the engineers' increasing the robustness and speed of their calculations. By deepening their level of information processing, they have arrived at the open fields of the romantic style of play, which has come to comprise one of the most fabulous discoveries in the modern era.

During the romantic age, sacrifices were made more intuitively and crudely, as well as to give relatively short-term compensation, whereas sacrifices made by the current generation of chess engines are subtler, more long-term and also rooted in robust calculations, which makes their aesthetics even more suited to the contemporary taste. That computer calculations would converge with the intuition of romanticists has been one of the most unexpected and surprising outcomes of the evolution of chess so far. Through analogies, we could be inspired to think of how something similar may be pending in the world of science as well. Just the way chess engines have fostered in the last couple of years a more daring and dynamic play among some of the world's best human players than ever before in history, computers may soon evolve into a stage where they would begin to hand humans ideas on how scientific research is to be approached, helping us craft more imaginative models and methods than we could have ever dreamt of. If this could really happen, then it is a logical question to ask and explore how artificial intelligence can outline the path that would lead to the old and forgotten, romanticist way of doing science, when art and analytics were merged into one.

A single greatest thing about Cervantes' novel about Don Quixote of La Mancha[104] is its ambiguity, which takes the reader by the hand to a crossroads, halfway between sympathizing with and pitying the protagonist. Which of the two sentiments will globally prevail largely depends on the era in question. In times when realism suppresses fantasy, as it does today in science and everyday life, readers will find the character of Don Quixote pitiful and ridiculous, and with it the very exhibitions of similar fancy. Yet, without a similar imagination, foolish or not, no science or art, which makes life worth living, would have ever been created. So hail to Don Quixote, says the romanticist, hops on his horse and rides off to another adventure. But before that happens for real, let us summarize what the new era of computer chess, which began at the point when computers became superior to the world's best players, has been teaching us. First, it has taught us that death by draw lies farther than humans thought, as exemplified by computer games at Elo 3500 ± 100 level, which, in fact, often end up with a decisive score. In science, likewise, creative ideas are infinite and to go beyond the beating on the humdrum drum of the same old paradigm, as we have in most scientific fields today, it takes a belief in the power of imagination à la that of Don Quixote's. The second major effect chess engines have taught us is that romantic play is not dead and that there is future for it. Compared to the days of the 19th century romanticism, though, when gambits and other sacrifices were expected to bring about an immediate compensation in initiative, today's sacrifices by the engines are significantly more long-term in character, the compensations for which are often impossible for humans to spot. Third, engines have taught us that algorithms could pinpoint the roads more enlightening than those paved by humans for other humans to walk on. Hence, in today's era when computers are still mostly used in sciences to achieve passive effects, be it for efficient data generation or mining, optimization of information processing or experimental protocols, or something else, if artificial intelligence were to be given a more creative role, the destination it may take us may indeed be beautiful. Harnessed to execute routine tasks alone, computers today make research labs only more industrial and more product-oriented, not more romantic and humane, for which to happen the next big stride in the engagement of artificial intelligence in scientific research must be facilitated first. When we consider that the level of imagination in today's natural sciences is exceedingly low, while conceptual copycats appear in ever greater numbers, it is tempting to dream of a time when computers would not only be able to replicate and facilitate the implementation of the existing concepts, but would also produce metalogical algorithms that would work at second-order levels of the scientific quest for knowledge creation. In other words, we are very near the time when computer programs will be able to predict the most effective courses of action in, say, optimizing the compositions of alloys for the best physical or biological response, then derive the experimental protocols for their synthesis and characterization, and, finally, compile all the results and interpret them in the format of a scientific paper, which is today, to start with, not too complex that the right software could not create it from scratch. In fact, in 2022, as the world was exiting the COVID-19 pandemic and entering the 'infodemic' of dissemination of misinformation through electronic media[105], my name appeared on a paper[106] that was obviously fabricated by a computer in the hands of a predatory publisher with the objective of including it in a fake scientific journal and then advertising it to legitimate potential authors ready to pay publication fees, but the quality of this forged paper was abysmal, yet in no more than a decade, it is conceivable that computers would be utilized by research labs to compose scientific papers based on their generated data. The next step would be to train the computers to think about the scientific progress from the higher, second-order plane, where a science on and about science is being created, at which point they may be able to provide guidance on where the effort is to be invested in the search for extraordinary discoveries and, in fact, play a creative role that would be at first on par with that of the most knowledgeable scientists in the field and would then go beyond it, in just about the same way as today's chess engines have exceeded any realistic expectations that the world's best players could compete with them.

When the potential of computers is put into this metalogical perspective, it becomes both frightening and exciting to think of how codes similar to those employed today by apps such as ChatGPT, Bing Chat, Claude or Bard will be used in the near future to program research methods, dig for literature information and write scien-

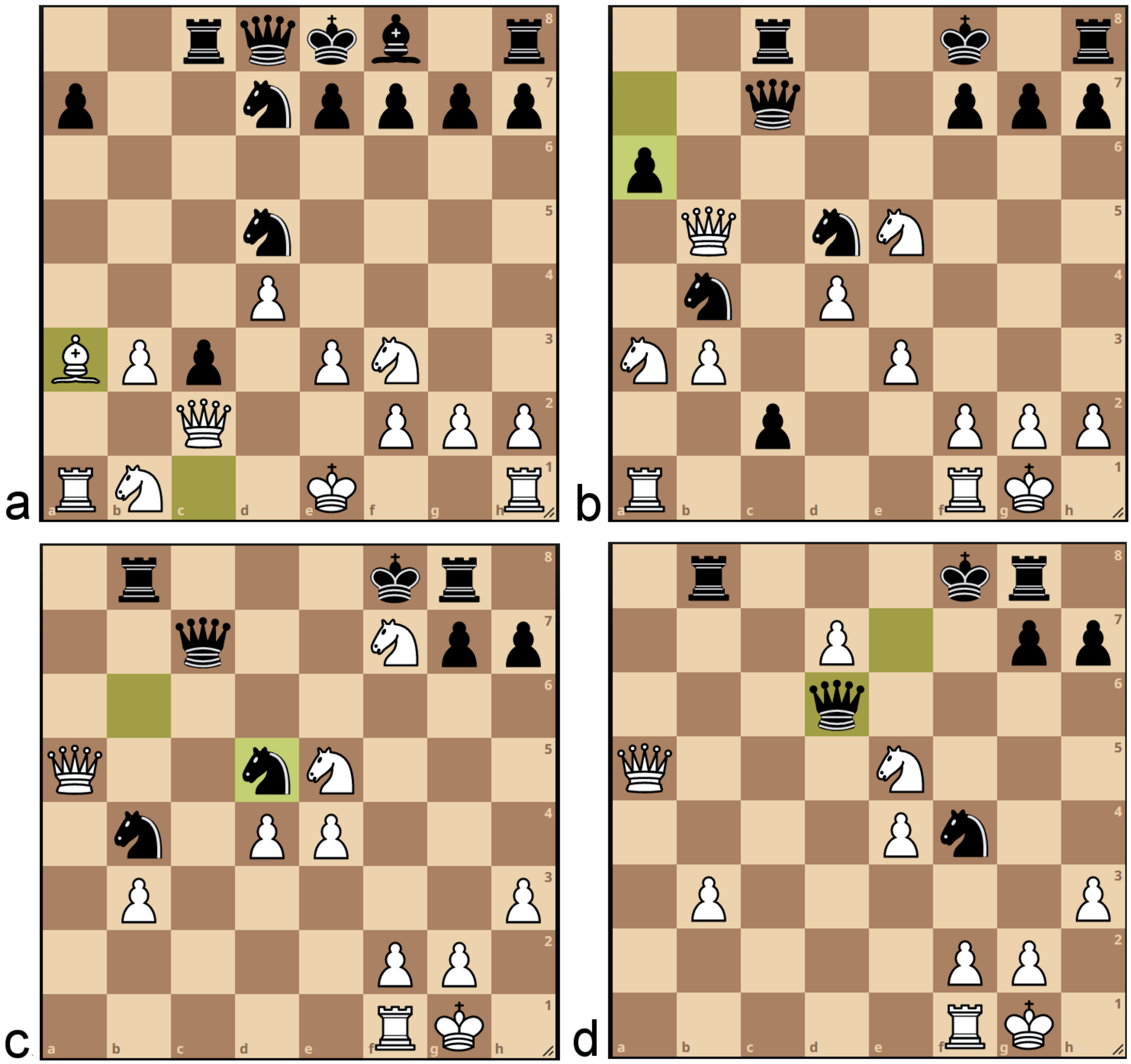

Figure 16. Stockfish 231014 (chess engine, Elo 3243) vs. Jonny 6 (chess engine, Elo 2960), Stage 2, Round 5 TCEC, 2014, 1 – 0. On move 13, instead of the more natural 13…Qa5 or 13…e6, Black plays in the digitally aged romantic style: 13…e5 (a). Next, in the position shown in (b), Black has just attacked the white queen with 20…a6. The squares c4 and d7 seem like the only two good spots for the white queen to move to, yet White plays 21.Qa4, seemingly allowing Black to promote the pawn, albeit planning to cut off the black queen with 21…c1=Q 22.Raxc1 Qxc1 23.Nac4 afterwards. On move 30, White offered Black the exchange of queens, yet once again White ignores the more human way of playing 30.Qa3 to pin the black knight and plays 30.Qa1 instead (c), calmly sliding the queen to the edge of the board, making a mysterious positional point thereby. While finding the pinning of Black's knight unnecessary, White voluntarily pins its own knight on e5, enigmatically, yet fearing no danger, by playing 37.Kh2, followed by 37…Ng6, in the position shown in (d). The quiet move of the king came with the threat of sacrificing the second white rook with 38.Rd1 to distract the black queen from the a3-f8 diagonal. After 38.f4 Ke7 39.Nc4 Qd4 40.f5 Nf8 41.Rf2 Qxf2, White did give away its second rook, but quickly captured both of the black rooks and ended up with two pawn advantage in a knight endgame.

tific papers, with only the finest oversight from humans, if any. The most optimistic point that the developments in chess can convey, through an analogy, is that the input of artificial intelligence may be not so creative at first, but over time it may gain a more romantic spirit than that typifying today's human researchers. Gradually, then, the natural scientist may once again start to openly appreciate the beauty of Nature and intermingle analyticity with art, in just about the same way as it was done until the mid-19th century, when objective realism became the dominant philosophy, in art and chess alike. Despite these promises, the questions will always remain, at least to the perpetual sceptics among us, if this pending romanticism will be just an allure to an artifice and yet another prepackaged lie through which humans will lose that little of naturalness and humanity that is in them now, or it will be a hand of the mystical intelligence dormant in the material world, reaching out to save us from the fall. The question like this is best left for future generations of philosophers of science and technology to untangle. It is in the nature of the romanticist to doubt the machine, everywhere and at all times, yet for now we can relish in the central analogy that has come from the evolution of the chess playstyle in the digital age, which is that these two's coming together, the man and the machine, may be indeed "the beginning of a beautiful friendship"[107].

WEEK 17, YEAR 2017: IDER VS. YIFAN

By 2010s, computers did not only begin to provide an essential creative input to chess, but they also started serving as an invaluable medium for casual and, at times, professional competitions. When most sports came to a halt during the COVID-19 pandemic, many annual over-the-board chess tournaments were held as planned, but in the virtual domain. Given the extensive spread of the global network of computers and their users, this has led to an unprecedented popularity of the game across all continents. Vishy Anand's becoming only the third world champion outside of the European continent, after Capablanca and Fischer, led to an explosion of interest in chess in India, while the game has undergone a recent increase in popularity in China as well.

Another positive effect of this all-around escalation of the interest in chess is that the traditional divisions between genders have begun to melt. This has led to the rise of some notable female players, such as Hou Yifan of China, the only female currently among the first 200 chess players in the world and the youngest women's world champion in history, which she became for the first time as a teen in 2010, at the age of 16. Overall, she is a four-time women's world chess champion, continuing the lineage of women's world champions from China, starting with Xie Jun in the 1990s and ending with the reigning world champion since 2018, Ju Wenjun. Yifan's style at times traces back to the romantic era, as shown in the example from her game against the Mongolian-born French international master, Borya Ider at the Gibraltar tournament in 2017, where she sacrificed her queen to secure a long-term positional advantage (Fig.17), a type of play that is atypical for humans, but seen commonly among today's computer engines. In natural sciences, likewise, especially in cultures that have traditionally been male-dominated in this field, we are witnessing a quiet revolution in terms of empowering women for more creative and recognized roles than it was the case in the past. If science were to regain its romanticist traits, its positivistic stance rooted solely in hardcore calculations will need to cede place partially to softer, more humanistic and qualitative mental routines, which is where the balance between the analytical and emotional intelligence, which the heterogeneous representation of genders naturally brings about, will become increasingly valued. After all, good analytical skills are a prerequisite for engagement in chess and sciences, but these skills alone, deprived of a holistic and emotionally intelligent component, fail their users and all else around them in a bigger picture. And if we take to heart and apply in practice David Bronstein's stance that "intelligence opposes the primitive principles of chess such as winning a tempo and gaining space", then the input to chess ideas and playstyles may open up to human beings with intelligences broader than the deadpan mental analytics, which would provide that final push in the chess culture away from the perception of the game as a sport and closer to the perception thereof as a form of art that is free to develop into unforeseen new directions, if only more imagination and less playing to win – which Tarrasch once renamed into "playing to lose"[108] – be invested in it. This is why the balance of genders, but also of complementary characteristics of a complete spectrum of intelligence within any given sentient creature, are to be spurred throughout the education and postgraduate training on every possible occasion.

Of course, great care must be taken whenever the freedom to practice science is being handed over to one group of people and taken away from others in a top-down manner, through external interventions. Meritocracy may thus cede place to mediocrity and frictions may be created between those very populations that were supposed to be brought together by the regulations, thus creating a diametrically opposite effect from the intended. This is seen clearly in today's natural sciences, where the divisions between genders are now greater than they have ever been in prior history. Such divisions, sadly, empower politicism in science and distance it from the knowledge about wonders of Nature that it is meant to explore, in as selfless and apolitical manner as possible.

Academic employments made possible through various governmental and institutional affirmative action

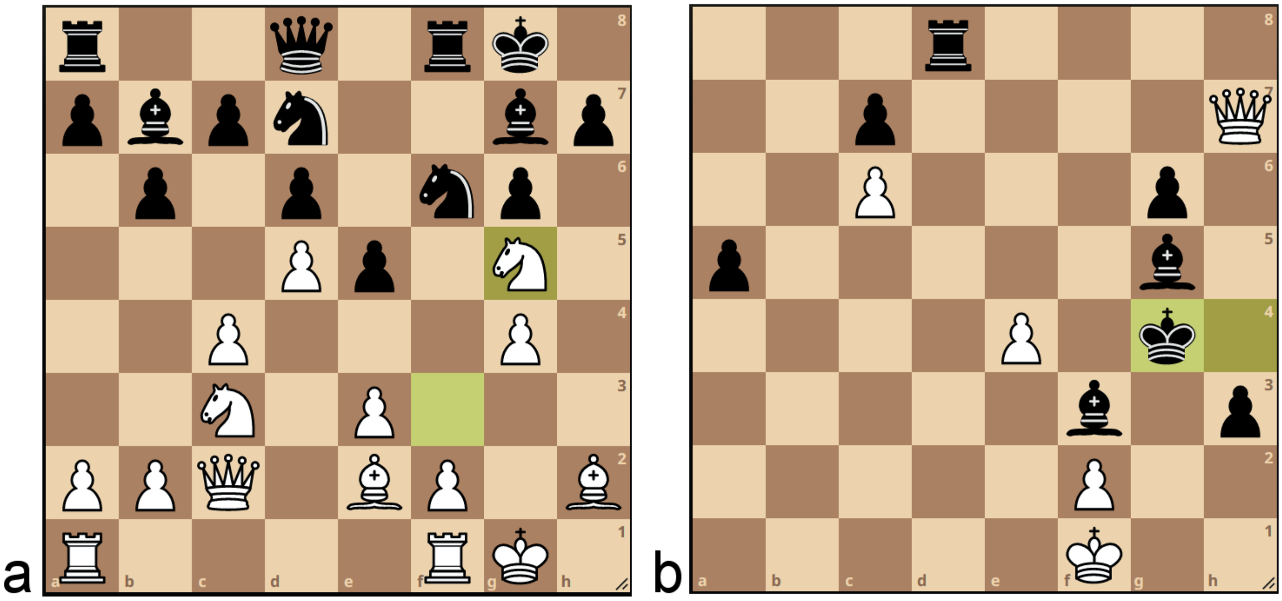

Figure 17. Ider vs. Yifan, Gibraltar, 2017, 0 – 1. Position on the board before Black's positional queen sacrifice with 15…Nxd5 16.Ne6 Nxc3 17.Nxd8. Black correctly estimated that the light-squared bishop implantable on f3, together with another minor piece, comprised a sufficient compensation for the queen. Final position of the game is shown in (b): the black king is sheltered from the checks while the checkmate threat with 53…Rd1# can only be stopped with 53.Qd7, which leads to checkmate in four after 53…Rxd7 54.cxd7 h2 55.d8=Q h1=R#.

and gender equity programs can be praised for diversifying the role models for students in natural sciences. To the romanticists at heart, they have also given hope that a wave of feminine sensibility would sweep over the rugged and harsh, masculinely carnivorous coast of the scientific culture and, in the long run, make it more emotionally intelligent, in the true, not merely managerial, sense of the term. Unfortunately, however, given the mechanism by which such appointments are secured, they have often led to strong inferiority complexes, which, in turn, have provoked the feelings of resentment and, ironically, exclusion, the very opposite of the inclusive effect intended to be achieved through such well-meant programs. The remedy to these impressions has been, tragically, found in the burrowing of a deep divide between genders and confinement to the circles of favoritism that include people on one side of this divide only. Meanwhile, to a casual outside observer, the current state of affairs in many academic institutions with regard to genders may appear as all but a far cry from a full-fledged trench war, harming, like any war, particularly those who, as all romanticists should, have stood in the middle of the fiery grounds, calling for the armistice and the arms of friendship to reach out and be held across these divides, an act very much natural at this time of unprecedented gender blending in all spheres of life. Importantly, also, whenever politics in lieu of science is given the primary role in the hiring process in a highly competitive environment, it should not surprise when the newcomers turn out to be more superior (micro)politicians and networkers than scientists in the most fundamental sense of the word. The benevolent nature of such employment programs notwithstanding, they have, sadly, infused the academic world with even more politics, which, we know, is the antipode of poetry and of the imaginative thought accompanying it. Gender-balancing policies may have been expected to soften the hard positivism of male-centered science of the past two centuries and open natural sciences to arts and humanities, but none of this has occurred and the implementation of these programs has only continued to make science more political and thus more ignorant and disinterested about the idea of reawakening romanticism across its antipoetic and politically poisoned pastures. The scientific culture may have been becoming less crude and more socially skilled on the surface of it, but at a dire cost of reducing its depth and leveling it by imposing the same professional standards uniformly across it, without leaving much room for the true diversity, namely the diversity of worldviews and not only of skins, genders and other surface features. This is where we are brought to one major downside of virtual communication, including that of playing chess online: namely, the inconspicuously reduced capacity to empathize with other people, especially those whose views are strikingly different from us. This effect can be evidenced through dramatic reduction in fair play standards in online chess as compared to those of classical, tête-à-tête encounters. And yet, without actively building up empathy, as through exposure to art in its various formats, divides in the world, including the faults occurring along the planes of contact of various –isms and other unilateral ideologies in the scientific culture, will continue to abide because those hands reaching out across them will be, simply, too little. On the contrary, it is in the celebration of littleness and everyday minutiae that this course will soon reach its final and climactic point.

WEEK 18, YEAR 2023: ARASAN 3E6E243 VS. IGEL 3.4.0

As the computer engines have become more robust throughout the past two decades, so has their style of play become increasingly romantic, bursting with strange and unexplainable sacrifices that prove right there, on the board, through analogy, that the material value of things matters little compared to the peculiarities of the position and the relationships between pieces. Machines, of course, have no emotions nor intuitive powers, and are programmed strictly to execute logical operations, which, ultimately, calculate the material value of pieces in a complex geometric arrangement. Yet, it is surprising that after passing through a sufficiently large complexity of relationships, this emphasis on sheer material value yields something significantly more sublime. To some, this is a proof that to perceive everything scintillating with mystical energies is to sense a reality realer than the objective realism, materialist in essence and imposed on us by social conventions. To others, this can be the proof of the work of the aforementioned pioneers of the first- and second-order cybernetics, from Ross Ashby to Warren McCulloch to Stafford Beer, who relished in the idea that spirit is but a complex web of neural relationships and nothing more. Like all the powerful and profound analogies, those discoverable in chess are indestructibly ambiguous.

That the relationships matter more than the material values of a collection of individual and isolated pieces is an enlightening insight *per se* and sufficient to secure place for chess in the pantheon of arts, shoulder to shoulder with music, painting, film and literature. Chess, in fact, can be viewed as a form of visual literature, the language of which is not alphabetic and grammatical, but rather composed of rules governing the movements of the pieces and operations among them. Thus, sitting among the mere two to three hundred members of the audience watching TCEC chess engine games live, which I have done over the years as much as I have listened to music, read books or watched movies, can be a source of great pleasure for the intellect. Teaching students how to find this satisfaction, as it is being argued here, can be beneficial for the creativity they are to learn how to exhibit in every domain of their lives, including the scientific. One example provided here of the style of play that future has in store for humans in not only chess, but also science, is given in Fig.18. The game[109], analyzed move by move, to an average human player or even a grandmaster, would seem like an encounter of two complete patzers, were it not only for the fact that the Elo ratings of the two engines exceed 3400, which is sufficient to beat today's super grandmaster singlehandedly. Here, however, lurks a cautionary tale for anyone exhibiting such and similar romantic traits in today's scientific climate, which is far from being accustomed to them. Namely, any such exhibitions are bound to be denounced as immature and unprofessional, and one such person will likely be excommunicated from the society as a madman or an outlaw. The only solace he should be able to find is that progressive spirits of the past, whose thinking was hundreds of years ahead of their times, were treated with similar carelessness and cruelty. To be rejected and expelled, in other words, is the fate we must be at peace with if the road in sciences that we are willing to walk on is romantic.

WEEK 19, YEAR 2023: LU VS. MKRTCHIAN

The quiet revolution in chess has led to gems produced out of over-the-board encounters of not only teenage boys (Fig.15) and female players (Fig.17), the general underdogs in open competitions, but of girls, too, one example of which is shown in Fig.19. Specifically, the example comes from the game between 12-year old Miaoyi Lu of China and 40-year old Lilit Mkrtchian of Armenia played in Round 11 of the First Serbian Women's League match day held at Stara Planina near Knjaževac in Eastern Serbia. The 18-move miniature evoking some of Paul Morphy's masterpieces from the romantic era may be not only a testament to the rise of a new style among chess players, but also the hint at where we ought to look at in search of mindsets naturally inclined to exhibit the romantic thought and bold, beautiful play, in chess and sciences alike: children.

Thinking about the evolution of the dominant chess styles throughout the history in terms of the style of world chess champions (Table 1) is customary amongst chess players and analysts, but it supplies any of such

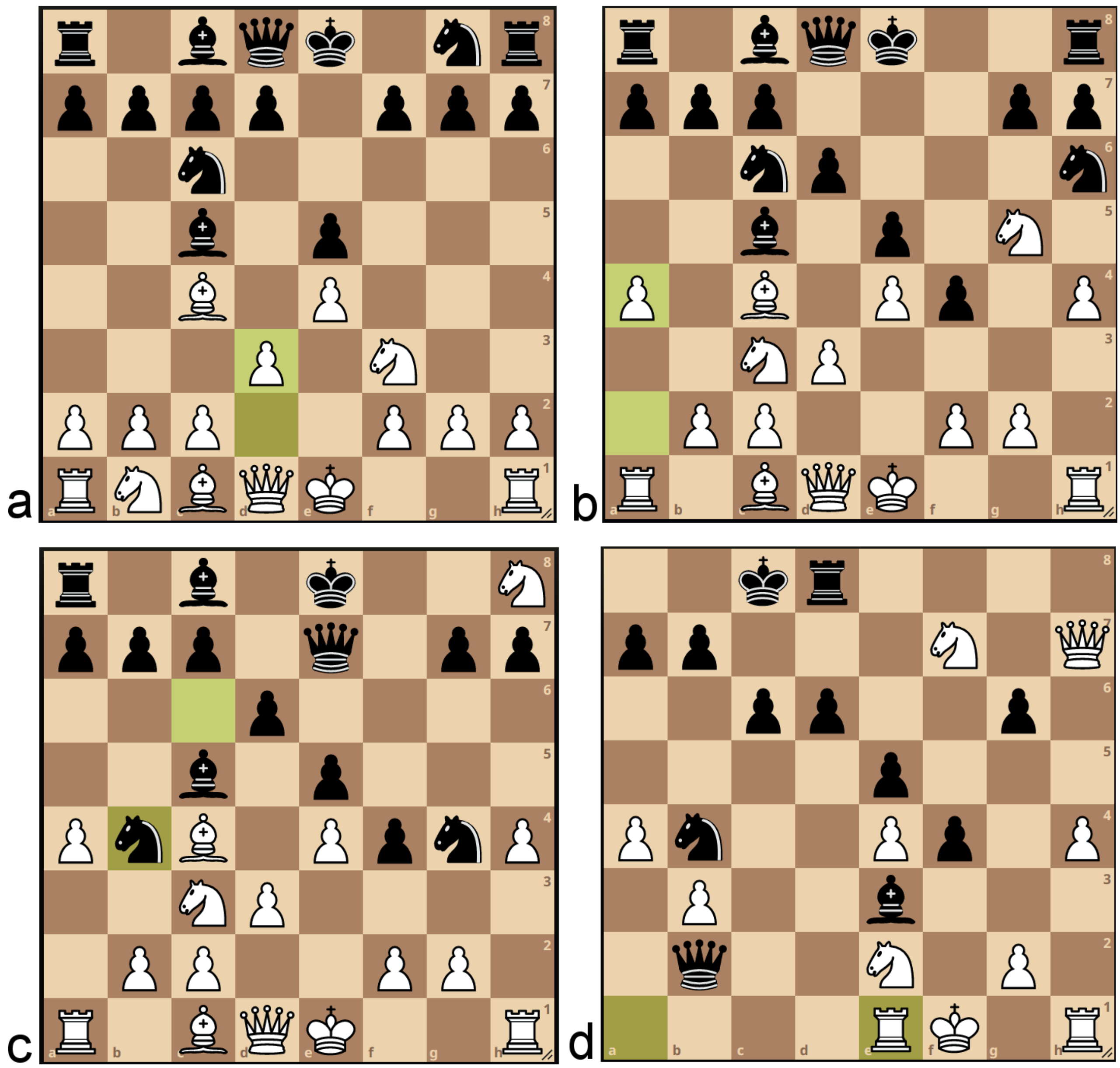

Figure 18. Arasan 3e6e243 (chess engine, Elo 3421) vs. Igel 3.4.0 (chess engine, Elo 3468), TCEC League 2 Igel Gauntlet, 2023, ½ - ½. Already on move 4, Black opted for a very aggressive and risky gambit by playing 4…f5, a type of move that had never before been played in a professional chess game (a). Then, on move 7, Black decided to remove the defender of the f7 square and attack instead with it White's own sensitive f2 square by playing 7…Ng4 (b), leading to a very sharp position. In the position shown in (c), White opted for a two-move sequence puzzling to humans: 11.Kf1 c6 12.d4 Bxd4. As the game developed into a mutual attack on two uncastled kings in the center, a position shown in (d) was reached, where checkmates were hanging on both ends of the board, and the game continued with 23…Qd2 24.Nxd8 Nc2 25.Rb1 Nd4 26.Qxb7+, after which a draw was reached via a perpetual check. From move 11 until move 40, when the threefold repetition occurred, Stockfish 15.1 evaluated each of the positions as 0.0, initially due to complexity and later due to a forced draw sequence.

discourses with a stale air of loftiness. Although one such method has been employed here as well to a considerable extent, as we approach the end of the course, it is time to dispel this habit and come to terms with the fact that extraordinary chess ideas and novelties can come far from the chess limelight. In science and art, this has been more of a rule than an exception: simply, the most creative new concepts tend to originate far more prolifically from small, intimate settings struggling with funds and resources than from mas-

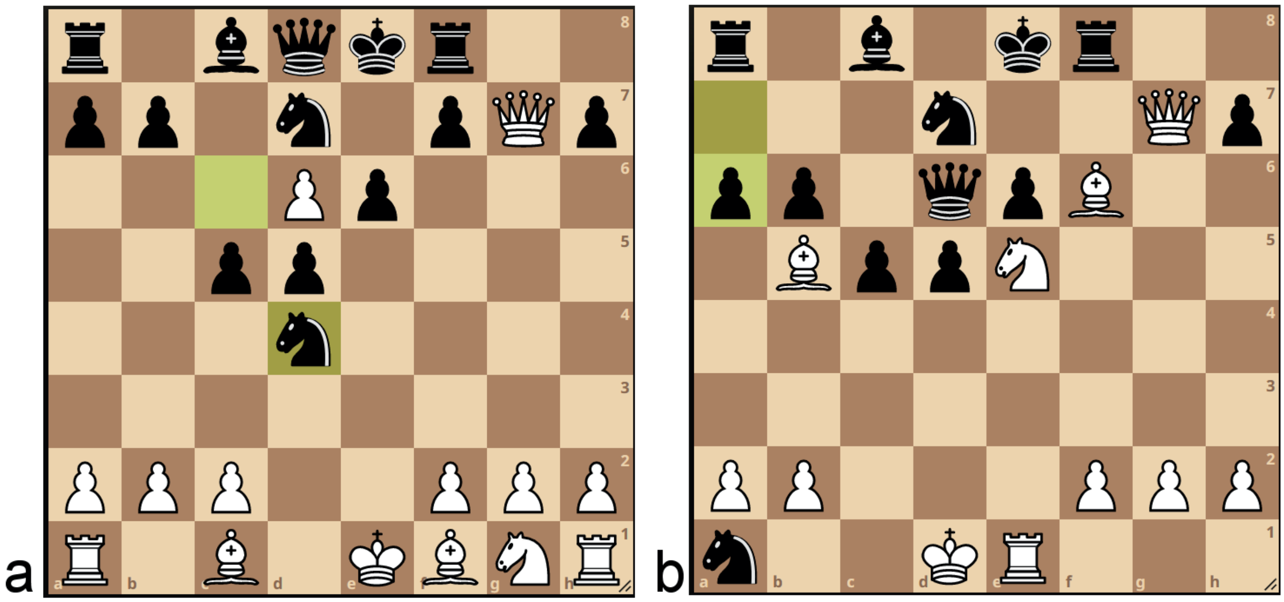

Figure 19. Lu vs. Mkrtchian, 1st Serbian Women's League, Stara Planina, 2023, 1 – 0. Position shown in (a) is right before White sacrificed her rook on a1 by playing 10.Nf3. Black would accept the sacrifice with 10…Nxc2+ 11.Kd1 Nxa1, after which White offered her bishop too with 12.Bb5 Qb6 13.Re1, at which point an unstoppable assault on the black king in the center commenced. On move 17, in the position shown in (b), White gave the final tactical blow to the opponent by playing 17.Nf7, attacking the black queen on d6 as the only defender of the e6 pawn. Saving the queen would lead to checkmate in one with 18.Rxe6#, and so Black played 17…Rxf7, but resigned after 18.Qg8+ because 18…Rf8 (or …Qf8) 19.Rxe6+ Re7 (or Qe7) 20.Rxe7+ Kd8 21.Rxd7+ Ke8 22.Rd8#. One move quicker checkmate would have come after 18.Rxe6 Qxe6 19.Qg8+, at which point White would have been two rooks and a minor piece down, yet winning in style.

sive, impersonal bureaucracies pampered by luxury. In search of revolutionary novel ideas, for example, the major film studios often contract smaller creative centers and then develop, themselves, these new concepts into something marketable on a more massive scale[110]. Similarly, big corporations in the pharmaceutical and biotech sectors routinely shrink their own centers for fundamental research and instead acquire small startups in the field that are more prone to come up with innovative solutions, but lack the momentum of a large enterprise to develop these solutions into a marketable product. In fact, the introduction of the novel ways of play by computers, which currently play bolder, more dynamic and more imaginative from the positional standpoints than humans have ever played, owes to the programming efforts carried out initially by moneyless enthusiasts in teenage bedrooms and garages and only then hitting the corporate mainstream. Personal computers, on which all these programming was done, had also been invented by amateur techies in search of engines that would be less expensive to make and maintain than the corporate mainframes[111]. And if we were to extend the timeline relevant for this discussion even farther, we would see that even chess *per se* was born and grew up to its current rule format owing to initially personal and later collective ingenuities whose efforts were neither guided by massive bureaucracies nor had any commercial interests in mind. This is why we have turned to lesser known players and amateurs, including children, toward the end of this journey, because everyone, everywhere, can create chess artwork, be it with computers or fellow humans for partners.

After all, it is not a coincidence that the two earliest examples of romantic play covered in Week 1 both originated from a casual setting, outside of the formal competitions. This is to say that romanticism, in chess and everywhere else alike, may be inherently tied to the darker corners of the world, behind the curtains, in the shadows of the limelight. In fact, as the course at hand has been progressing toward its climax and the conclusion, so have we started to gradually drift from the mainstream sources of chess games to the more obscure ones, in parallel with this grand reawakening of the romantic spirit in chess. The final chess game analyzed in this course will, therefore, come from the most obscure of such possible sources, that is, from a playroom where children equal to or under the age of 10, barely trained in chess, will produce a game with the assistance of a computer, from one and only attempt, especially for the purpose of this occasion.

Symbolically, the path traversed by the course is from one informal, laidback setting to another, but also from games played by grownup experts to those played by amateurish children. Implicitly, this is to say that rescuing science and science education from everything unromantic plaguing them in this day and age may require parting with the province of the interest of adult professionals and landing straight into the heart of the kingdom of children, for whom a course like this was designed in the first place. This path can also be a reminder to those who consider themselves professors and mentors in today's corporate academic climate that monetary measures of success are vain and that in lieu of titles and egos, students are those who should occupy seats on the pedestal of every instructor's attention, in and out of classroom, for it is around their suns that all educational efforts should revolve.

WEEK 20, YEAR 2023: USKOKOVIĆ, T. VS. USKOKOVIĆ, E.

The chronology traced in this course started with the peak of the romantic era in chess in the mid-19th century, when chess was slowly becoming a global sport and a professional call for many, then proceeded to the age of 13 undisputed chess champions, from Steinitz to Kasparov, continuing through the period when the chess federations split and then reunited, and emerging in the end in the current computer era of the game, when engines have spontaneously rediscovered the romantic style that lay buried under the carpet of comparatively dry, insipid play for nearly a century and a half. The chronology at hand also highlighted how the burst in the popularity of the game has meant that ages and genders that do not comprise the mainstream sources of most illustrious chess games can be relied on in producing magnificent pieces of art on the chessboard. On the lookout for such obscure sources of chess excellence, we drifted from the world's top chess players and engines to female chess players first and then to children.

Extrapolating this chronology to the near and the distant future, chess becomes less of a sporting contest driven by the petty desire to win and more of a co-creative and collaborative form of art. This humanization of chess, in turn, would begin to attract less of the competitive egomaniacs and more of the artistically inclined individuals to it, a change of heart that would be nice to see in natural sciences as well. Simultaneously, chess of the future envisaged here, like the scientific culture, should also become less exclusive and elitist and more open to the creative input of everyone, including children. This is especially so because arguably the best way to fight back the bleak corporate powers that have uprooted science from its renaissance roots and turned it into a callous business for the capitalist moguls and their subservient sycophants to profit from is through displays of unrestrained, rebellious childishness. Besides, since the spiritual goal of the human beings is to trace the way back to that paradise lost of the childhood mind, thereby expelling all the irksome adult traits and becoming infinitely pure, like when one was a child, then it is logical to end this course with children, on our laps and on the highest vistas of inspiration. Moreover, since chess is the everyday game of everyday people, in quest of this inspiration, we can also look at children who need not be trained in chess. This is because even the most amateurish chess games can be analyzed position by position for interesting variations. And so here is an example of the first and only game played especially for this occasion as an experiment that is to show that even a randomly played game of chess by two pupils in this experimental class, children ages 7 and 10, with only the basic understanding of chess principles, can produce an endless source of amusement and inspiration for the analyst. Although a children's chess game played without any external input or advice can be infinitely entertaining to watch and analyze *per se*, the game presented here allowed the children to consult the computer choices in the course of the game, as in analogy with today's correspondence chess, where no restrictions exist regarding the use of computers by the players. Specifically, children were able to consult opening books during the opening stage and then select one out of five choices provided by Stockfish run on the *chess.com* analysis engine for each subsequent move. In such a way they were able to create a solid game of chess instead of a festival of blunders, notwithstanding, again, that both can be equally instructive and enjoyable to analyze. In the university setting, similar games of chess at this stage in the course could be produced by students or by teams thereof, just as well as many of the topics covered each week could be investigated and presented by them in the form of active learning projects[112].

To accompany every chess game with a fair, friendly and objective postgame analysis is a part of chess etiquette. Through such analyses, students are instructed about this most critical of all phases that must be passed on the way to deepening one's understanding of chess: the postgame analysis. As a result, chess games, be they produced by children or by students as in-class activities or homework assignments, should be subjected to collective analyses employing constructive discussions and didactics. Each such game need not be analyzed to the finest detail, but it is advisable that it be analyzed to an extent that is sufficient for students to gain the impression that every game of chess, regardless of who has played it, can be an infinite source of insight and novelty. Such was, naturally, the case with the game created by the two children specifically for this occasion (Fig.20). Symbolically, the game proceeded with the building of the tensions in the center, but only up to the 19th move played by White, Be4, after which a series of exchanges occurred, the pawn symmetry was reestablished and a dead draw position was reached. The game could even be classified as a boring or a friendly draw and most masters or grandmasters would discard it as uninteresting, but this is where the doors to wisdom and semantic fields extending beyond those of sheer smartness, cleverness or high IQ open before students – in the awareness that everything, even the most lackluster things in life, hide invaluable treasures somewhere in them.

The game started off as an Indian defense, but by the third move it transposed to queen's gambit accepted, which was followed by a hint at an apparent ease with which children stumble upon innovative ideas. This hint came in the form of an opening novelty introduced inadvertently by White already on move 4. Here, White played a move that appears to had never before been played at the professional level: 4.Bd2 (Fig.20a). The move e4 presents the most common choice in this position, followed by Nc3, Qa4+ and g3, while Na3, a4, Bg5, Bf4, Qc2 and Nbd2 have been the obscure choices, yet Bd2 is not even among them, having not been played once in an official game. The move cannot be classified as a mistake by any means, as it does not give any tangible advantage to Black, so the question is why it has never been tested in professional practice before, where taking the opponent out of the opening book is an essential tool used by masters and grandmasters, and especially so since the move comes very early in one of the oldest openings in the history of chess. In queen's gambit accepted, the dark-squared bishop is normally either the last minor piece to develop or the first to be exchanged for the knight on f6, yet children here reverse this habit, as they do many other ones, and prompt the adults to think about something that they have not thought before. Like all opening ideas, this one must have a multifold purpose, but two of them stood out after the analysis. Namely, in the case of the clearing of the center after …c5 and dxc5, White could bring the dark-squared bishop to c3 and then combine this with the usually placed light-squared bishop on c4 and queen on c2 to create a powerful attack along the diagonals on the short-castled black king, with one possible variation from the opening being 1. d4 Nf6 2. c4 d5 3. Nf3 dxc4 4. Bd2 c5 5. dxc5 e6 6. e3 Bxc5 7. Bxc4 0-0 8. 0-0 Nc6 9. Qc2 b6 10. Bc3 (0.0). Otherwise, if White continues to play with an isolated queen's pawn, aka *isolani*, then the bishop could be implantable on the e5 square, as, for example, after playing 17.Bf4 and 18.Be5 instead of 17.Ne5 and 18.Rc2, which were played in the game. Whereas the latter sequence of moves was a prelude to simplification of the position, the bringing of the bishop to e5 would have come with a lot of opportunities for attack, especially because the bishop is stable on this outpost and cannot be exchanged by Black's playing 17…Be7 and 18….Bf6, as after 17.Bf4 Be7 18.Be5 Bf6 19.Bxf6 Nxf6, White sacrifices the rook with 20.Rxe6+ (Fig.20b) and Black is lost or checkmated after 20…fxe6 21.Bg6+ Kf8 22.Qb4+ Kg8 23.Qe7 Be4 24.Qxa7 Rxa7 25.Rc8+. Yet another, third potential benefit of 4.Bd2 may be its acting as a prophylaxis against any Nimzo-Indian ideas, which are most meaningful for Black in the Catalan system of queen's gambit, where White opts out of an attack on the kingside and tries to create a positional pressure in the center instead by fianchettoing the light-squared bishop.

In any case, after 19.Be4, the tensions in the position fizzled out before they had a chance to evolve into a combinatorial middlegame. First the minor pieces and then the major pieces were exchanged, and a completely draw rook endgame transitioned to a king and pawn endgame, where the two kings blocked each other's entrance to the opponent's camp, at which point the draw was agreed on. Despite that, the late opening and early middlegame stage, when the game could have developed into something completely different can be a gateway to infinitely valuable instructions about chess and, through analogies, about every possible aspect of our sciences and our lives. For example, if White pushed the f pawn to f5 instead of playing 19.Be4, the game would have proceeded in a much more exciting way than it did, just as it would have if White responded to rather passive 10…Qa7 with the dynamic pawn sacrifice, 11.d5 (Fig.20c), with a possible continuation being 11...Nxd5 12.Nxd5 exd5 13.e4 d4 14.e5 Be7 15.e6 fxe6 16.Ng5 Nf6 17.Bxh7 Rxh7 18.Nxh7 c4, leading to a very unbalanced position and a decent advantage for White. In any case, the final position was reached (Fig.20d) and even there, children could study why, for example, the pawn breaks with a4 or …a5 lose for both White and Black, respectively, unless for very specific positioning of the kings. They could also learn the principle of opposition, a form of zugzwang that is essential to king and pawn endgames, as, for example, by

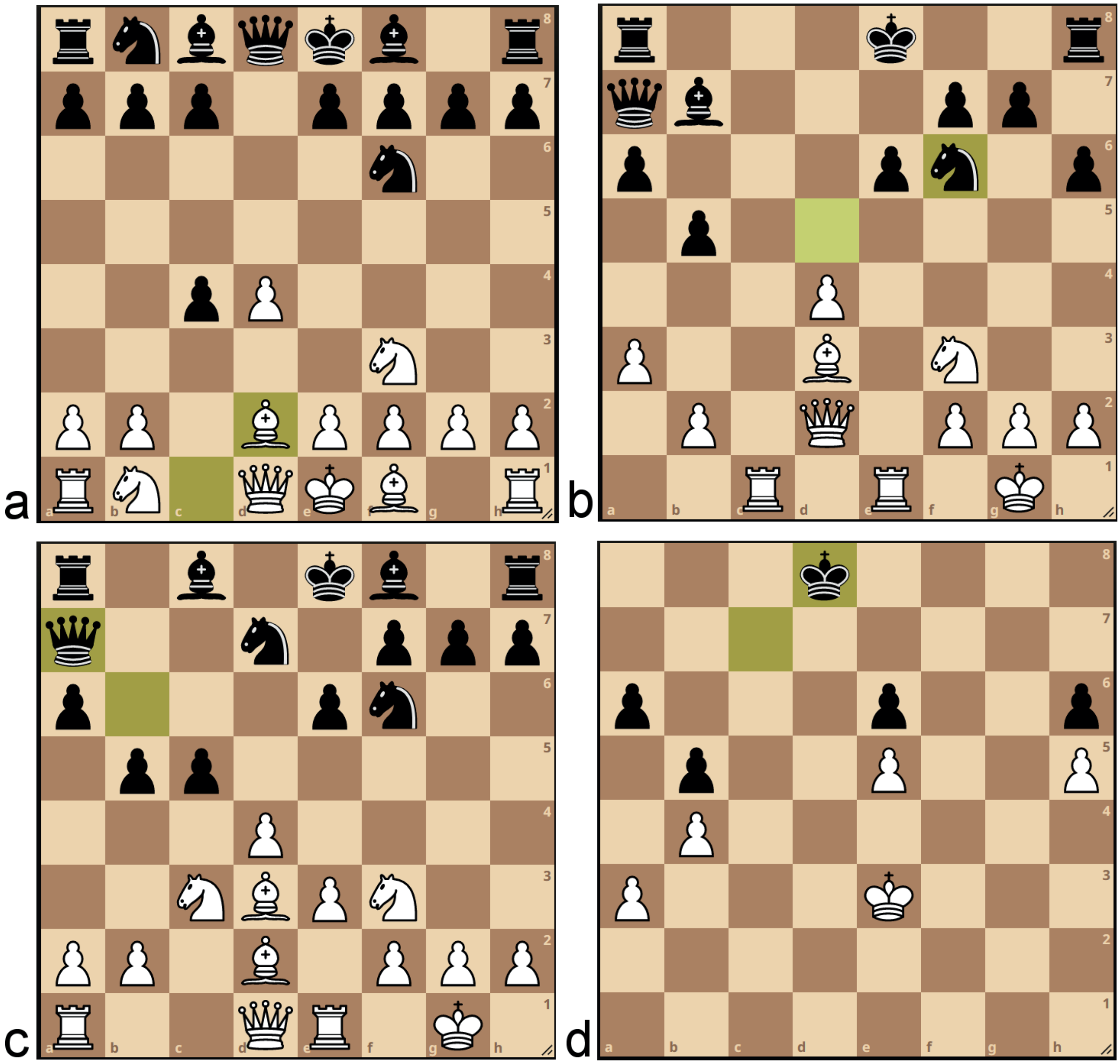

Figure 20. Uskoković, T. vs. Uskoković, E, Irvine, California, April 23, 2023, ½ – ½. Children's propensity for the inadvertent production of novelties comes to prominence with White's playing 4.Bd2 (a), a completely new move already on move 4 in one of the oldest openings in chess history: queen's gambit accepted. Next, instead of playing 17.Ne5 in the game, White could have repositioned the dark-squared bishop to e5. Its exchange for Black's dark-squared bishop would come with a lot of opportunities for the attack, as immediately after the exchange following 17.Bf4 Be7 18.Be5 Bf6 19.Bxf6, if Black took back with the knight by playing 19…Nxf6, the position in (b) would be reached where White wins with an elegant rook sacrifice: 20.Rxe6+ fxe6 21.Bg6+ Kf8 22.Qb4+ Kg8 23.Qe7 Be4 24.Qxa7 Rxa7 25.Rc8+ Ne8 26.Rxe8#. Before the tensions in the center were released through the exchange of all the minor pieces and the reestablishment of symmetric pawn structures, White did have a chance to push the game to more dynamic territories, and one opportunity was to respond to comparatively passive 10…Qa7 with the dynamic pawn sacrifice, 11.d5, in the position shown in (c), the goal of which would be to break through the center and launch a timely attack on the uncastled and insufficiently protected black king. The final position in (d) was reached after 55 moves and the players agreed to a draw. PGN: 1. d4 Nf6 2. c4 d5 3. Nf3 dxc4 4. Bd2 e6 5. e3 Nbd7 6. Bxc4 a6 7. O-O c5 8. Bd3 b5 9. Re1 Qb6 10. Nc3 Qa7 11. a3 cxd4 12. exd4 Bb7 13. Be3 Nd5 14. Rc1 h6 15. Qd2 N7f6 16. Nxd5 Nxd5 17. Ne5 Bd6 18. Rc2 Qb6 19. Be4 Nxe3 20. Rxe3 Bxe5 21. dxe5 O-O 22. Qc1 Bxe4 23. Rxe4 Qd8 24. g3 Rc8 25. Rxc8 Qxc8 26. Qxc8 Rxc8 27. Re3 g5 28. b4 Kg7 29. Kg2 Rc2 30. h4 gxh4 31. gxh4 Kg6 32. Rf3 Rc7 33. Rf6+ Kg7 34. h5 Rd7 35. Rf4 Rd8 36. Kg3 Kf8 37. Kg2 Rd7 38. Rf3 Rd5 39. Re3 Ke7 40. f4 Rd2+ 41. Kg3 Rd5 42. Rc3 Rd1 43. Rc7+ Rd7 44. Rxd7+ Kxd7 45. Kf3 Kc6 46. Ke4 Kd7 47. Kd4 Kc6 48. Ke4 Kb6 49. f5 Kc7 50. fxe6 fxe6 51. Ke3 Kb8 52. Kf3 Kc7 53. Ke3 Kd7 54. Kf4 Kc7 55. Ke3 Kd8

understanding why White's playing 56.Kd4 in the final position would force Black to play either 56…Kd7 or 56…Kc8, but not 56…Kc7, which would lose due to the opposition rule after 57.Kc5. Symbolically, the board, in this final position, is populated by 8 pawns only, which is the number suggestive of infinity if it only be laid down and made "lazy". Seeing this, a parent may be prompted to conclude that children split infinity among themselves, and if we seek infinity, we best start searching for it in children[113]. And then, if children, at this stage in the game, want to give up playing competitively, they could still promote up to five pawns into all kinds of pieces and have them hop around the board and play and practice checkmates and stalemates and what not. In other words, like in this final position, there is beauty and there is life in everything that seems dead on the surface, if we only dig deep into it.

As one final note, it is worth adding that this emphasis on children converges with my personal research oeuvre since the beginning of the 2020s, where children and everyday settings have provided centerpieces for the aforementioned research projects from various fields, ranging from psychology to ornithology to art to physics, chemistry, biology and materials science. This is where science of the poor[114] and science of and for the children[115] of this world were born, as romantic as the sky can swallow it. For, under the open skies, hand in hand with children, I am free to say, the best research of my life was done. This is the brightest of the bright notes on which this course and this walk through the history of chess and its analogies with science can end, and will end.

And now, at the end of this walk along a thin rope, with one hand reaching out to a world of chess and another to a world of science, bless yourself with a ♥ or ♥♥, tell yourself all is love, and walk on, into the sunset. Who says that we cannot end a scientific paper on this romantic note? If we want the romantic era to be reawakened, then we must start off by being the beauty and the freedom that we want to see in the world, of science and everything else alike.

Even if our last gasp of freedom is that of a randomly typed string of symbols, it is what it is. It is beautiful, as all else is.

So goodbye, bhgyhiuhunjft 4duckhgeeyincdh, and safe ride.

CONCLUSION

Semantically, chess is multidimensional; a board game for entertainment to one, a mental sport to others, and a geometrically complex and logically enriched narrative art to yet others, amongst infinite other points of view. Although it contains definite artistic elements, the study of chess requires a rigorous scientific approach, too. Perceived as a fusion of the rigor and analyticity of science and the aesthetics of arts, chess can serve as a prolific source of analogies translatable to practices exercisable in various arts and sciences.

Here, an academic course taking students on a journey through chess history and drawing simultaneously parallels with the evolution of trends and major experiments in natural sciences (Fig. 21) was being portrayed in a narrative, easily digestible format, with a supposedly captivating flow. The journey was circular, beginning around the peak of the romantic era in chess, in the mid-19th century, and ending with the current, digital age where chess playing style has been heavily influenced by computer engines, which, surprisingly to many, have begun to play often in the same romantic style that has been traditionally tied to the beginnings of chess as an art form. The astonishing discovery of the most artistic of chess playstyles by engines, through unprecedentedly deep calculations, serves as a call to celebrate the fusion of art and science in every human discipline.

The story about the evolution of chess playstyles presented here is a sign of brighter things to come. It is a sign that natural sciences, which have been divorcing steadily from anything artistic since the age of enlightenment, may rediscover their romantic, renaissance and neoclassical roots if only computers and artificial intelligence evolve past the point where human intelligence could keep up with their ideas, both the routine one and the inventive, and be given a more creative role than they play today. Although it is conceivable that humanity will have to pass through many a dark tunnel, where algorithms would be used to control the global and local economy and politics for selfish means, serving the vilest in man, eventually we will emerge to the sunlit shore, if only the analogies with the history of chess drawn here were correct. Until then, we, the romanticists at heart, need to be patient and put trust into that very same thing that the romanticists have been most sceptic about: the mind of the machine.

In this interim, in lieu of impatience, we can harbor historical outlooks and do what we can to poke the scientific community and try to awaken it from a long slumber on the flowerless bed of logical positivism. The romantic movement in the 19th century arts emerged from a reaction of poets and soulful thinkers against the epidemics of dry rationalism that was gripping people's minds in the age of enlightenment and scientific revolution, and although it left inerasable traces in arts, it was a short-lived undercurrent in natural sciences, sporadic

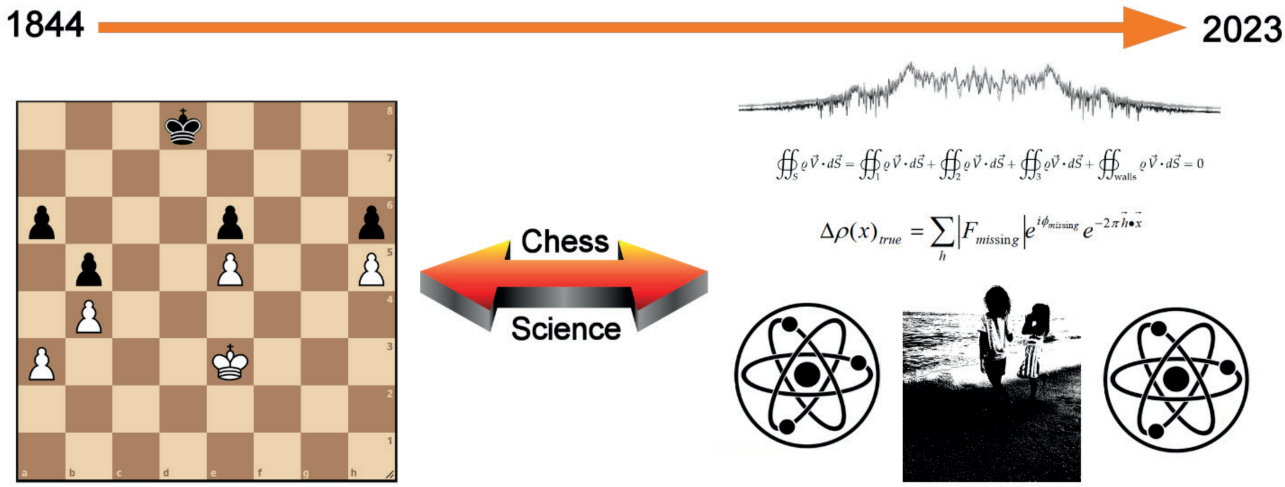

Figure 21. From the mid-19th century to this day, the trends in chess and in natural sciences have twined around one another, paving way for the informed insight into chess history to be relied upon as a predictor of the future developments in sciences, and *vice versa*. The course exploring seminally these historical parallels has ended with the current point in space and time, when the romantic spirit, long gone missing from natural sciences, is being called for by the poets. If anyone will be able to bring back this enchanting spirit and reintegrate it into the equations of modern science, it is, as the content of this course insinuates, children, both real and those who have vowed to always, under all circumstances, remain children at heart.

on the surface at best. Yet, it was a form of activism, and activism may be what is needed to restore the romantic spirit in the heart of the scientific enterprise today. Crusading capable of converting the unbelievers to believers and proprietors and politicians into poets and poetesses, of course, is always sparked best by those who have suffered most under the tramping of the establishment, a category to which myself, an expellee from the academic system because of the romantic stands I took on its podia, proudly belongs. This, as the end comes near, is a call to arms, but not of steel. These are arms of soul instead that should be wrapped gently and caringly around the new generation of intellectuals as we show them the beauty of the romantic worldviews while avoiding the trap of the temptation to convince them in the righteousness of these views or enforce any of their elements upon them.

The academic course presented here has emerged from one such aspiration to share with the newcomers to the world of natural sciences the view of the trajectory of the evolution of these sciences and how they extrapolate into something far more beautiful than what the dominant scientific culture of the day has to offer. The idea that this course could inspire them to take part in this new wave has brought about an unspeakable satisfaction to this instructor during the design stage. Last but not least, the course delivered in a condensed form to a group of young chess aficionados and budding scientists was met with approval. This conclusion was deduced based on an informal assessment of the student satisfaction following the accelerated exposure to the blueprint of this course. The attendees' opinions were overwhelmingly positive and they asserted the usefulness of the course for inspiring and preparing them for careers in natural sciences. This has given confidence to the instructor that the conversion of this course to a higher education setting would be viable and that students in all sciences would benefit from it. Because an intermediate knowledge of chess, if not absolute proficiency, alongside the familiarity with basic scientific principles will be required from the students and the teachers interested in attending this course to comprehend its content and engage in meaningful discussion, it would be preposterous not to assume that this process of transition would bring about inevitable challenges. However, with a sensitive approach to instruction, it can still be assured that curiosity is provoked, inspiration enkindled, and no student left behind in the learning process. Where we, as the community of scientists and chess enthusiasts, go from here in the attempt to test this all out and subject this correlation between trends in chess and trends in natural sciences to further scrutiny is future. This future, however, like any other, as the chronological storyline elaborated here implies, can be glimpsed only if we know history well enough and can trace with confidence its lines beyond the horizon.

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Feature Articles

Exploring the Potential of *Dacryodes Edulis* Leaf Extract as Natural Colourant on Polyamide Fabrics: Extraction, Characterization and Application

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Abstract. There is a growing demand for sustainable and eco-friendly alternatives in the textile industry, particularly in search of natural colourants derived from plants. This research study investigates the extraction and characterization of natural colourant from the leaf of *D. edulis* and explores its application to polyamide fabrics. Laboratory experiments, such as solvent extraction was performed to obtain the colourant. The extraction process was optimized using Response Surface Methodology-Central Composite Design (RSM). The dye was isolated and characterized using vacuum liquid chromatography, UV-Vis spectrophotometry, high-performance liquid chromatography and Fourier-transform infrared spectroscopy. Physical properties such as light fastness, perspiration fastness, rubbing fastness and wash fastness were assessed to determine the durability and stability of the natural colourant on the fabrics. The results indicated that the optimal conditions for dye extraction are 65.9 °C and 2 hours, providing feasible parameters for replication. Examination of the natural dye obtained from the isolated fraction, revealed the presence of carbon-carbon double bonds (C=C), carbonyl (C=O), ester (-COO), aldehyde (CHO) and hydroxyl (-OH) groups; with rutin, isoquercetin and tannic acid as its major compounds. The isolated dye exhibited an absorption peak at 403 nm. The ratings for the treated fabrics varied from fair to good and very good. The light fastness ranged from 4 to 6, perspiration fastness and wash fastness ranged from 2-4, and rubbing fastness ranged from 3-5. On the other hand, the untreated fabrics had ratings, with a range of 2-5 for light fastness, 2-4 for perspiration fastness and wash fastness and 1-4 for rubbing fastness, it was also observed that the colour strength values of mordanted fabrics were deeper than those of the unmordanted fabrics. These results indicate that the dye obtained from *D. edulis* leaf has considerable potential as a source of natural dyes. These findings contribute valuable insights into the extraction, characterization and application of natural colourants, promoting a shift towards more sustainable and eco-friendly practices in the textile industry.

Keywords: Natural dye, Extraction, Characterization, Response surface methodology, *Dacryodes edulis,* leaf, Polyamide, fabrics

1. INTRODUCTION

Humanity has progressed from the stone age to the information age and is now making deep inroads into the environmental age, thus, there is a growing interest in natural dyes [1]. These dyes, derived from plants, animals or minerals without chemical processing, come from various parts of plants and insects [2]. While the invention of synthetic dyes in 1856 led to a decline in natural dyes [2], synthetic dyes have notable drawbacks, including carcinogenic properties and allergic reactions. In contrast, natural dyes have numerous advantages such as being eco-friendly, non-toxic, and aesthetically pleasing and even possessing medicinal properties [3]. This has further fueled interest in natural dyes for textile colouration, especially in countries with strict environmental regulations [4].

The dyeing process of natural dyes can be significantly improved using a Soxhlet apparatus which allows for the efficient extraction of concentrated dye solutions from natural sources. This method is advantageous as it recycles the solvent, producing a more potent dye extract and minimizing waste [5]. Studies have shown that the Soxhlet extraction method can yield higher dye concentrations, which in turn can lead to better colour yield and fastness properties on the dyed textiles [5].

In industrial processes using natural dyes, it is crucial to characterize these compounds efficiently and non-destructively. Fourier-transform infrared spectroscopy (FTIR), High-performance liquid chromatography and UV-vis Visible spectrophotometry are commonly employed techniques due to their affordability, ease of use, reliability and ability to provide detailed data [5; 6].

Natural dyes exhibit distinct properties and affinities for different fibers which can be enhanced through various dyeing techniques. For instance, indigo, derived from the Indigofera plant, is renowned for its vibrant blue hue and finds common application in wool and nylon textiles [7]. Nylon, being a synthetic polyamide with a structure resembling protein fiber, can benefit from modified dye baths containing additives that enhance dye affinity for synthetic materials. Onion extract, derived from the outer papery skin of onions, contains flavonoids and tannins, serving as a natural dye. Onion dyeing yields vibrant shades and possesses antibacterial properties [8]. Lac insect is another natural dye used for wool and nylon. Its rich, deep hues enhance colour and fastness properties in these fabrics [9]. Madder, a plant-based dye, imparts a vivid red colour and similarly improves colour and fastness in wool and nylon fabrics [10]. These natural dyes offer sustainable alternatives to synthetic dyes, thereby reducing environmental impact and promoting eco-friendly textile production.

One promising natural dye source is *Dacryodes edulis* (G. Don) H. J Lam (Figure 1), also known as safou in the Republic of the Congo and Angola, plum in Cameroon and Ube in Nigeria, is a native fruit tree primarily found in the humid lowlands and plateau regions of West, Central Africa and Gulf of Guinea countries. This evergreen tree can grow up to 18- 40 meters in the forest but typically stays under 12 meters in plantations Along with producing edible fruits, the bark, leaves, stems and roots of *Dacryodes edulis* are used as local medicine for treatment of certain diseases [11]. Since natural dyes have been the subject of extensive research, including the extraction and application of natural dyes from orange peel and lemon peel on cotton fabrics, as well as the extraction of natural dyes from selected plant sources and its application in fabrics [3, 12]. This study explores the extraction, characterization and potential application of *D. edulis* leaves as a natural dye source.

Figure 1. *Dacryodes edulis* leaves

2. MATERIALS AND METHODS

2.1 Chemicals and reagents

Laboratory grade ferrous sulphate ($FeSO_4$) was used as mordant while a diluted solution (2 g/L) of sodium carbonate (Na_2CO_3) was used to adjust the pH of the dye solution to 7. Reference detergent A (ECE phosphate-free standard detergent powder wfk-Testgewebe

GmbH) soap (5 g/L) was used for the wash fastness test. Hydrochloric acid (37% fuming HCl), *n*-hexane, acetonitrile, ethyl acetate, glacial acetic acid, ethanol, Wagner's reagent (potassium iodide and iodine crystal) and sulfuric acid, all of which were of analytical grade and obtained from Merck (Darmstadt, Germany) were utilized in this study.

2.2 Plant material

The plant material used in this research was *Dacryodes edulis* leaves (Figure 1) collected as discarded waste from households in Kiagbodo, Delta State. The leaves were identified and given a voucher number (No. 0614) by Dr. B. E. Omomoh of the Department of Forestry and Wood Technology at the Federal University of Technology, Akure, Nigeria. The leaves were washed with distilled water without squeezing to remove debris and dust particles and then dried in the sun for a period of three days, as exposure to UV radiation can enhance colour development through photooxidation processes [13]. Once thoroughly dried, the leaves were pulverized into a powder, using a manual blender (Porkert Manual Grinder No.32), and stored at room temperature until further use.

2.3 Optimization of extraction parameters

Preliminary Soxhlet extraction was carried out while varying two parameters (solvent and temperature). Four solvents namely: ethanol, dichloromethane, 0.5 M sulphuric acid with ethanol and distilled water, were used. Briefly, the colourant was extracted using 200 ml of each solvent, which was placed in a round bottom flask, heat was supplied through a heating mantle to the flask and 10 g of the powdered waste leaves was held in a paper thimble which sat in the Soxhlet apparatus. Extraction was done at different temperatures (40, 50, 60, 70, 80 and 90 °C) for one hour each. Thereafter, the extracts were allowed to cool down and an aliquot of each was analyzed using a UV-vis spectrophotometer to obtain the absorbance.

Statistical analysis was conducted using a Central Composite Design [14]. Optimization was performed using five levels: -α, -1, 0, +1 and +α (Table 1). A total of 13 experiments were conducted, with two independent variables: temperature (X_1) and extraction time (X_2) to check the reproducibility. To describe the behaviour of the crude dye system, an empirical second-order polynomial mode was used, and its coefficient was determined using Equation 1.

$$Y\% = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1 + \beta_4 X_2 + \beta_5 X_1 X_2 \quad (1)$$

Where: Y is the response variable or output; β_o, β_1, β_2, β_3, β_4, β_5, are the coefficients of the model that need to be estimated while X_1 and X_2 represent the interaction terms of the independent variables. All analytical tests were carried out in triplicate. Statistical analysis was performed using the MODDE software. Data were analyzed using the analysis of variance (ANOVA), and a *p*-value lower than 0.05 was considered significant in surface response analysis.

Table 1. Experimental range and levels of independent process variables

Parameter	Symbol	Coded levels				
		-α	-1	0	+1	+α
Temperature (°C)	X_1	65.9	70	80	90	94.1
Extraction time (Hr)	X_2	0.6	1	2	3	3.4

The optimal extraction parameters obtained from the response surface methodology-central composite design were used to carry out a second batch of extraction using a Soxhlet apparatus [15]. Thereafter, the extract so obtained was then separated using vacuum liquid chromatography.

2.4 Isolation procedure

Vacuum liquid chromatography (VLC) was performed using the method described by Paranagama and Ndukwe *et al.* with slight modifications (Figure 2) [16,17]. To ensure optimal packing density, the VLC column was dry packed with thin layer chromatography (TLC) grade silica under vacuum. Subsequently, ethanolic crude extract of *Dacryodes edulis* leaves was prepared, along with silica gel mesh, and loaded onto the column. The elution process was carried out by sequentially using 300 ml of suitable solvent mixtures (mobile phase), beginning with a low polarity solvent (100 % *n*-hexane); subsequently, the polarity was gradually increased by adjusting the solvent ratio (*n*-hexane-DCM in ratios of 3:1, 2:2, 1:3), 100% DCM, DCM-ethyl acetate (3:1, 2:2, 1:3), 100 % ethyl acetate, ethyl acetate-EtOH (3:1, 2:2, 1:3) and 100 % EtOH) between each fraction collected. The column was pulled dry after each mobile phase to ensure proper separation.

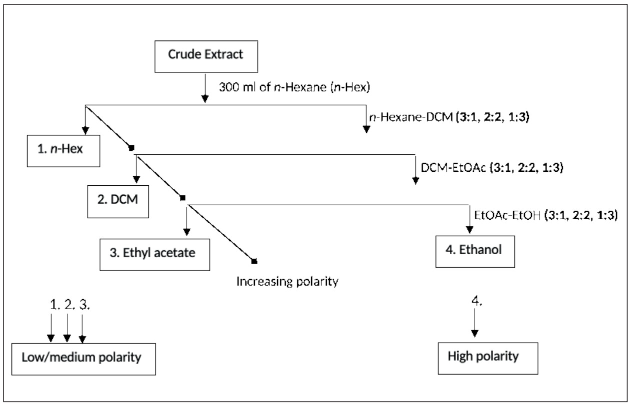

Figure 2. Framework of VLC model

2.5 Phytochemical screening tests

The phytochemical examination was conducted on the isolated dye of *D. edulis* leaves using standard procedures to detect the following bioactive compounds: alkaloids, flavonoids, glycosides, terpenoids, tannins and steroids [17,18].

2.6 UV-visible analysis

The UV-VIS-NIR scanning spectrophotometer UV-3101PC (Shimadzu) was used for all spectrophotometric measurements. All measurements were carried out using quartz cells 10-mm at room temperature (25±2 °C) and changes in their absorption (400-800 nm) were noted.

2.7 HPLC analysis

The HPLC analysis was carried out using Agilent 1260 infinity HPLC system with a photo diode array detector (Agilent Technologies, Palo Alto, CA). The chromatographic separations were carried out using an Xbridge^{TM} Shield RP_{18} column (4.6 mm I.D. × 150 mm, 3.5µm) (Waters, Milford USA), with column oven temperature maintained at 20 °C [19]. The mobile phase comprised of 0.1 % acetic acid (Solvent A) and 100 % acetonitrile (Solvent B). The mobile phase flow rate was 1.0 ml/min with gradient elution. The percentage composition of Solvent B was maintained at 20 % for 3 min, gradually increased to 38 % for 24 min, further increased to 90 % for 1 min and maintained at 90 % for 5 min, followed by equilibration to the initial composition for 6 min. the injection volume was 10 µL and UV absorbance was monitored at 365 nm.

The software used for FTIR data collection was the Infrared Data Management (IRDM) system. The infrared spectrum was recorded at room temperature with a PerkinElmer Fourier Transform Infrared Spectrometer, Model spectra 100 series (Perkin-Elmer Corporation, Norwalk, CT, USA), equipped with a deuterated triglycine sulfate (DTGS) detector and controlled by a PerkinElmer PC. The instruments were maintained in constant humidity to minimize water vapor interference. Drops from each standard were placed on the attenuated total reflection element and scanned. After each scan, the ATR diamond was rinsed three times with acetone and dried with soft tissue before adding the sample; Calibration spectrum was obtained from 64 scans at a resolution of 2 cm^{-1} with strong apodization through 3500-1000 cm^{-1} frequency region. The spectrum was rationed against the background air spectrum. All the scans were done in triplicate with the spectrum recorded as absorbance and stored on a disk.

2.8 Preparation of the fabrics

The use of fabrics such as wool and nylon 6 were selected for this study due to their compatibility with natural dyes [20] with wool being particularly sustainable. Nylon 6 and wool were immersed in a detergent solution for approximately 60 minutes and then thoroughly rinsed with tap water until all detergent was removed. Afterwards, the clean fabrics were washed with de-ionized water, gently squeezed and dried in an air oven at 60 °C. Finally, they were stored in a vacuum desiccator, ready for use.

2.9 Mordanting

In this experiment, the mordanting process was conducted before dying, referred to as pre-mordanting. The aim of pre-mordanting was to enhance the adsorption of the dye and ensure a strong bond between the dye and the fabric. The commonly used mordant, such as ferrous sulphate ($FeSO_4$) was selected. Initially, the wool and nylon fabrics was immersed in warm water (approximately 46 °C) for 30 minutes to relax the fibers, making the fabrics more receptive to mordanting and dyeing. 8 fabric samples were taken for mordanting. 10 gm/ l $FeSO_4$ was taken in dye pot separately and it was heated with the samples for 1 hour at a temperature of 100 °C. After 1 hour the fabrics were let for conditioning for 24 hours. After washing these samples are dried (Figure 3).

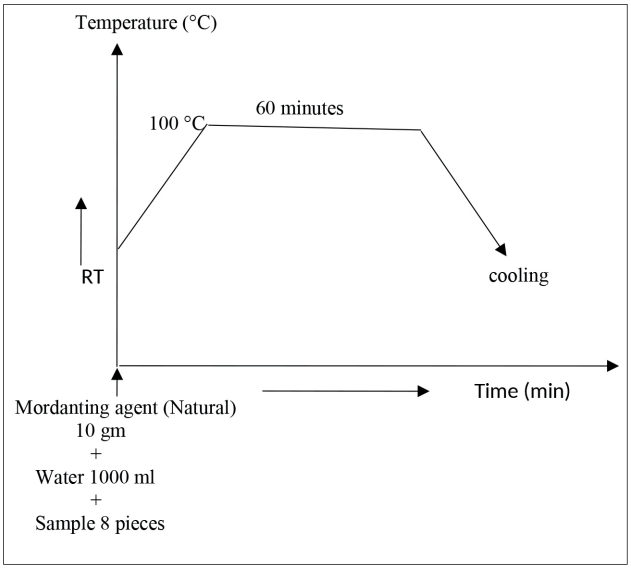

Figure 3. Process curve for mordanting with natural mordant

2.10 Dyeing procedures

The dyeing procedures were performed following the general dyeing method [21]. A fabric-to-dye ratio of 1:10 was chosen based on the weight of the fresh natural dyes extracted and the fabrics used in the experiment. The fabric was immersed in a dye bath composed of 0.25% aqueous solution of the dye. The dye liquor ratio of 1:10 was kept constant for all samples, and the pH value of the dye bath was optimized depending on the type of raw material. For *D. edulis*, the pH values were adjusted by adding drops of sodium hydroxide or hydrochloric acid to achieve pH levels of 9-10 and 3-4, respectively. The temperature of the dye bath was gradually increased (about 1 °C) until it reached 100 °C and was kept at this temperature for about 60 minutes. Afterwards, the dye bath was allowed to cool to around 60 °C. The dyed fabric was then squeezed, thoroughly rinsed with water and air-dried.

2.11 Determination of wash fastness of dyed samples

The dyed specimens of wool and nylon fabrics with a dimension of 5 cm × 4 cm were placed between two pieces of undyed white fabrics of the same dimension. Three pieces were stitched together around the edges to create a composite specimen. The composite specimen was agitated with ten steel balls in a 100 ml beaker, containing a solution of 5 g/L soap and 2 g/L soda ash with a liquor ratio of 1:50 as stipulated by ISO 3 standard (ISO 105-C10:2006). The washing process was carried out at 60 ± 2 °C for a duration of 30 minutes in a launder-o-meter. The composite specimen was then rinsed, separated and dried. The change in colour of the test samples and the staining of the adjacent undyed white fabrics were evaluated using the grey scale, with references to the ISO 9001 2000 group.

2.12 Determination of light fastness

Strips of the fabrics and the blue wool standards were cut and mounted on cardboard paper. Half portions of the specimens were covered to obstruct the light source from getting to that portion. The specimens were exposed to natural daylight in a south-facing direction at an angle of 45 °C, sloping from the horizontal, for a duration of 72 hours in accordance with ISO105B01:2014 standard. After 72 hours, the specimens were removed and the extent of their fading was assessed by comparing them to the blue wool standards.

2.13 Fastness to perspiration test

The fastness to perspiration test evaluates the ability of textile fabrics to resist colour fading or running when exposed to perspiration. This test was carried out according to ISO 105-EO4 standard method, two perspiration solution (acidic and alkaline); the acidic solution consists of sodium chloride (NaCl, 5 g/L), disodium hydrogen orthophosphate dehydrates (Na_2HPO_4 2.5 g/L) and histidine monohydrochloride monohydrate. The pH of the solution was adjusted to 5.5 while the alkaline solution consists of $C_6H_9O_2N_3.HCl.H_2O$ (0.5 g/L) and is adjusted to pH 8 using 0.1 N sodium hydroxide (NaOH). The liquor ratio for the test was 20:1.

2.14 Determination of fastness to dry and wet rubbing

The dyed samples' dry and wet rubbing fastness was tested using a Crock meter in accordance with ISO 105-X 12:2001 standards. The specimen was placed in the Crock meter and a piece of standard white cloth (starch free 96.100 cotton fabric of a long type) was used to rub against the coloured specimen. This rubbing process was carried out under controlled condition of pressure and speed. For both the dry and wet tests, the rubbing fingers were covered with white cloth and moved back and forth for a total of 20 rubbing strokes. The colour transferred onto the white cloth was compared with a Grayscale for alteration of colour, consisting of grades 1-5.

2.15 Evaluation of color strength

Estimation of colour strength of the dyed fabrics are carried out by determining the K/S values using a computer colour matching system (CS-5, Applied colour system, USA). The value of reflectance (R) in the visible wavelength region is measured using the ACS spectrophotometer. The value of reflectance (R) of the dyed fabric is measured at the wavelength of 420 nm and also the K/S value of the sample is found directly from the instrument. Every dyed sample is measured in the same way and the K/S values are obtained directly from the instrument, which follows the Kubelka-Munk theory as in equation (1).

$$K = (1-R)^2 \quad (1)$$

3. RESULTS AND DISCUSSION

The research was carried out to ascertain the chemical constituents of the dye from *D. edulis* leaf, which would help identify the compounds responsible for the colouration. Analytical techniques (HPLC, FTIR and UV-vis spectroscopy analysis) were employed for this purpose. The isolated dye was applied to polyamide fabrics, along with additives like mordant, and the dyed fabric was tested for wash fastness, light fastness and perspiration fastness.

3.1 Optimal extraction condition

The process of optimizing experimental conditions, such as the temperature of the extraction process, is crucial for the efficient extraction of target compounds. In this study, the Soxhlet apparatus was optimized to achieve the desired results. The temperature of the extraction process was carefully adjusted within a range of 30 °C to 90 °C. The impact of this temperature variation on the yield of colouring compounds is depicted in Figure 4. The graph presented a clear narrative of the experimental results. The results revealed that ethanol consistently produced higher yields of colourants from the leaf of *D.edulis* when compared to the other solvents. As a result, it was concluded that ethanol is the optimal choice for extracting natural colourants from *Dacryodes edulis* leaf. Additionally, the efficiency of water and dichloromethane were found to be lower than the mixture of ethanol and 0.1 M H_2SO_4 (1:1). The difference in efficiency could be attributed to the acidic nature of H_2SO_4, which helps break down the dye molecules, enhances the solubility of certain compounds, and facilitates the extraction process. The findings of this study, support the research conducted by Al-Alwani et al. [22], who compared the effectiveness of nine solvents for extracting natural dyes from cordyline, pandan and dragon fruit (*Cordylline fruiticosa, Pandannus amaryllifolius* and *Hylocereus polyrhizus*). The solvents tested were n-hexane, ethanol, acetonitrile, chloroform, ethyl ether, ethyl acetate, petroleum ether, n-butyl alcohol and methanol. The study aimed to assess the optimal extraction conditions. The results indicated that ethanol and methanol were the most suitable solvents.

Figure 4 demonstrates that the extraction efficiency of the ethanolic extract remained relatively constant between 30 °C and 40 °C. However, a marked increase in colour yield was observed from 40 °C to 70 °C, suggesting that temperature plays a significant role in the extraction efficiency of colouring compounds, a finding that aligns with previous research [23]. However, a slight yield reduction beyond 70 °C suggested possible pigment degradation in certain dyes at excessively high temperatures [21].

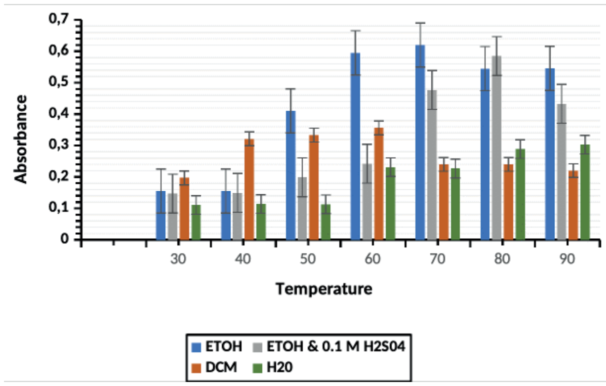

Figure 4. Effect of Temperature on the Concentration of D. edulis leaves Dye when Extraction Solvents (Mixture of Ethanol and 0.1 M H2SO4, ETOH, DCM and H20) and Time (1 hour) are Kept Constant

3.2 Central composite design model and data analysis

The central composite design is useful for establishing a mathematical model that relates the parameters of interest (such as temperature and extraction time) to the results obtained [23]. The CCD design consisting of 13 experimental runs was employed to investigate the optimization of natural dye extraction from *D. edulis* leaf using ethanol. It was observed from the experimental data (Table 2); that the yield obtained for 2 hours of extraction time at 65.9 °C was notably superior to that obtained with other experimental variables. A high value of this (0.8186) indicates a better extraction performance.

Table 2. The Independent Variables and their Corresponding Levels of Dye Extraction from D. edulis Leaf

Std	Run	Factor 1	Factor 2	Response 1
		A: Temperature (°C)	B: Time (Hr)	Absorbance
9	1	80	2	0.6316
8	2	80	3.4	0.5338
12	3	80	2	0.6310
11	4	80	2	0.6296
5	5	65.9	2	0.8186
6	6	94.1	2	0.5216
4	7	90	3	0.4764
10	8	80	2	0.6316
7	9	80	0.6	0.5417
2	10	90	1	0.5200
3	11	70	3	0.7227
13	12	80	2	0.6319
1	13	70	1	0.6937

The statistical significance of CCD model was assessed using analysis of variance (ANOVA). The results of ANOVA, summarized in Table 3, indicate that the applied model was successful in navigating the design space. According to the data in Table 3, the correlation coefficient (R) has a high value of 0.9999, suggesting that over 99.08 % of the sample variables can be attributed to the variables in the model, with only 0.92 % of the total variance remaining unexplained. Adjusted R^2, which takes into account the sample size and several variables, is commonly used to evaluate the goodness of fit in models with multiple independent variables [24, 25]. In this case, the adjusted R^2 of 0.9999 is in close agreement with the predicted determination coefficient (Pred R^2 = 0.9998). It is worth noting that due to the large number of terms in the model and a relatively small sample size, the adjusted R^2 might be smaller [25]. The F-value and P-value also confirmed the significance of the model. A larger F-value and a smaller P-value indicate a more significant model. The obtained F-value of 25921.44 suggests the model's suitability and adequacy. Additionally, evaluating the residuals can provide insight into how well the model satisfies the assumptions of ANOVA [25, 26].

Table 3. Analysis of Variance (ANOVA) for the Response Surface Quadratic Model

Source	Sum of Squares	Df	Mean Square	F-value	P-value	
Model	0.1095	5	0.0219	25921.44	< 0.0001	Significant
A-Temperature	0.0882	1	0.0882	1.044E+05	< 0.0001	
B-Extraction time	0.0001	1	0.0001	98.31	< 0.0001	
AB	0.0013	1	0.0013	1560.20	< 0.0001	
A^2	0.0026	1	0.0026	3067.73	< 0.0001	
B^2	0.0153	1	0.0153	18099.41	< 0.0001	
Residual	5.912E-06	7	8.446E-07			
Lack of Fit	2.520E-06	3	8.400E-07	0.9906	0.4822	Not significant
Pure Error	3.392E-06	4	8.480E-07			
Cor Total	0.1095	12				

C.V. = 0.1496 %; R^2= 0.9999; Adjusted R^2= 0.9999; Predicted R^2=0.9998; Adeq Precision =546.2502

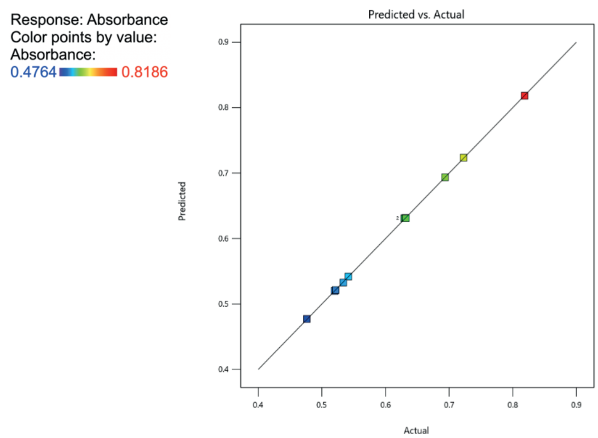

Figure 5. Correlation between actual experimental and predicted values

Figure 5 shows the predicted value for the response (outcome or result), the actual value or response. The diagnostic plots clearly demonstrate that the experimental values are in close proximity to the model predicted values. This observation suggests that the model is therefore a good fit for the experimental data. In support of these findings, a case study conducted by Hassani et al. [26] highlights the importance of diagnostic plots in data analysis. The study emphasizes the need to examine the proximity of data points to the regression line as an indicator of the model's performance. By incorporating the diagnostic plot, the researchers were able to validate the accuracy and suitability of their models for the experimental data.

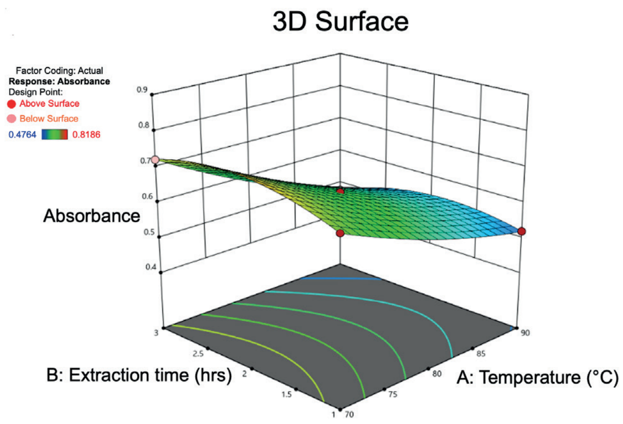

Figure 6. 3D plot for temperature and time interaction

The 3D response surface is commonly used in response surface methodology (RSM) to illustrate the interactive effects of factors such as temperature and extraction time on the response variable [27; 28]. Figure 6 presents a 3D plot that illustrates how temperature and extraction time interact to influence the response variable. The curved surface that peaks in the center and tapers off towards the edges suggests a strong interaction between two independent variables (extraction time and temperature), where the response variable reaches a maximum value (0.8186) at the peak. By analyzing this plot, the optimal conditions for achieving the maximum dye extraction were observed at a temperature of 65.9 ^{o}C and an extraction time of 2 hours, as indicated in the 3D surface plots. However, exceeding an extraction time of 2-3.5 hours or a temperature range of 65.9 - 75 ^{o}C leads to a decrease in dye extraction rate which is consistent with the principle of thermodynamics and kinetics governing chemical reaction.

3.3 Phytochemical screening of the isolated dye

The process of extracting and conducting phytochemical screening on natural colourants from plant materials is a crucial step in identifying bioactive compounds. The crude dyes extracted from *D. edulis* leaves using a Soxhlet apparatus were analyzed, with the aim of identifying specific compounds. The crude extract obtained using ethanol was partitioned into thirteen fractions through the application of vacuum liquid chromatography [16]. Vacuum liquid chromatography (VLC) is a highly effective technique for the separation and purification of various compounds. The focus of this analysis was to identify key metabolites such as tannins, flavonoids and alkaloids, all of which are known for their diverse biological activities and dyeing potential. Upon screening, Fraction 13 which was the dye was found to contain metabolites such as tannins, flavonoids, terpenoids, steroids and alkaloids. However, cardiac glycosides were not detected. A comprehensive overview of the identified phytochemical groups in the fraction is provided in Table 4. It is noteworthy that these findings coincide with a prior investigation which also reported the presence of alkaloids, flavonoids, steroids, and terpenoids in the leaves of the same plant [29]. This consistency not only validates the reliability of the results but also supports the potential application of these compounds.

Table 4. Phytochemical Groups Present in *D. edulis* leaf Dye

Phytochemical group	VLC Fraction 13 (Isolated Dye)
Alkaloids	+
Steroids	+
Tannins	+
Flavonoids	+
Terpenoids	+
Cardiac Glycosides	-

Key: + Present, - Absent

Table 5. Constituents of the Isolated Dye from *D. edulis* Leaf

Compound	Phytochemical Group	Concentration (µg/ml)	Percentage composition Per Group
Benzoic acid (1)	Flavonoids	21.465	17.7
Isoquercetin (2)	Flavonoids	15.472	12.8
Rutin (3)	Flavonoids	19.563	16.1
Apigenin (4)	Flavonoids	17.250	14.2
Chlorogenic acid (5)	Polyphenols	47.500	39.2
Berberine (6)	Alkaloids	14.413	16.0
Vincristine (7)	Alkaloids	8.137	9.04
Vinblastine (8)	Alkaloids	10.165	11.3
Strictosidine (9)	Alkaloids	57.276	63.6
Tannic acid (10)	Tannins	40.082	100

Table 6: Colour Fastness to Light for *D. edulis* leaf

	Ferrous sulfate Mordant		Control Unmordanted	
Sample code	Wool Colour Change	Nylon 6 Colour Change	Wool Colour Change	Nylon 6 Colour Change
DA 2 %	5	4	3	2
DA 4 %	4	6	3-4	3
DA 6 %	6	5	5	3-4
DA 8 %	5	6	5	4

Key: DA-dye concentration, 1-very poor, 2-poor, 3-fair. 4-moderate. 5-good, 6-very good, 7-excellent, 8-outstanding

Table 7: Colour Fastness to Wash for *D. edulis* leaf

	Ferrous sulfate Mordant		Control Unmordanted	
Sample code	Wool Colour Change	Nylon 6 Colour Change	Wool Colour Change	Nylon 6 Colour Change
DA 2 %	4	2	2	2
DA 4 %	4	2-3	3	2
DA 6 %	3-4	4	3-4	3-4
DA 8 %	4	4	4	4

Key: DA-dye concentration, 1-poor, 2-fair, 3-good. 4-very good. 5-excellent

Table 8. Colour Fastness to Perspiration for *D. edulis* leaf

	Ferrous sulfate Mordant				Control Unmordanted			
Sample code	Wool Acid	Wool Akaline	Nylon 6 Acid	Nylon 6 Alkaline	Wool Acid	Wool Akaline	Nylon 6 Acid	Nylon 6 Alkaline
DA 2 %	3	2-3	3	4	2	2	2	2
DA 4 %	4	3	2-3	2	3	3	2	3
DA 6 %	3-4	4	3	3	2-3	4	3-4	4
DA 8 %	4	4-5	4-5	4-5	3	4	3	4

Key: DA-dye concentration, 1-poor, 2-fair, 3-good. 4-very good. 5-excellent

Table 9. Colour fastness to rubbing for *D. edulis* leaf

	Ferrous sulfate Mordant				Control Unmordanted			
Sample Code	Wool	Wool	Nylon 6	Nylon 6	Wool	Wool	Nylon 6	Nylon 6
	Dry rubbing	Wet rubbing	Dry rubbing	Wet rubbing	Dry rubbing	Wet rubbing	Dry rubbing	Wet rubbing
DA 2 %	4-3	3	4	2	2	1	2	1
DA 4 %	3-4	3	4	3	2	1	3	2
DA 6 %	4-5	4	4-5	3	3-4	2-3	3-4	2
DA 8 %	5	4	5	4	4	3	4	3

Key: DA-dye concentration, 1-poor, 2-fair, 3-good. 4-very good. 5-excellent

Table 10. Colour coordinate values and colour strengths of wool and nylon 6 samples mordanted with $FeSO_4$ and dyed with dye isolate from *D. edulis* leaf

Sample	Concentration of mordant, %	K/S	L*	a*	b*	C*	H*
Non-mordanted wool		4.2	42.8	3.8	4.5	12.5	52.5
Iron Sulphate ($FeSO_4$)	2	6.7	32.5	5.6	7.6	15.6	53.2
	4	7.5	30.7	6.4	8.7	16.5	53.5
	6	8.6	28.8	7.5	9.2	18.6	53.8
	8	9.8	27.5	5.2	9.8	19.7	62.5
Non-mordanted nylon 6		4.0	34.7	3.7	4.6	11.6	56.2
Iron Sulphate ($FeSO_4$)	2	5.2	36.8	5.2	5.7	13.5	52.3
	4	6.3	34.5	5.6	7.6	15.2	51.3
	6	7.5	33.6	5.8	8.7	19.3	52.4
	8	8.7	30.7	7.0	9.5	20.4	57.6

Key: K/S- Strength of the shade of dyed sample, L* Brightness, a* Extent of redness, b* Extent of yellowness or blueness, H-Hue angle

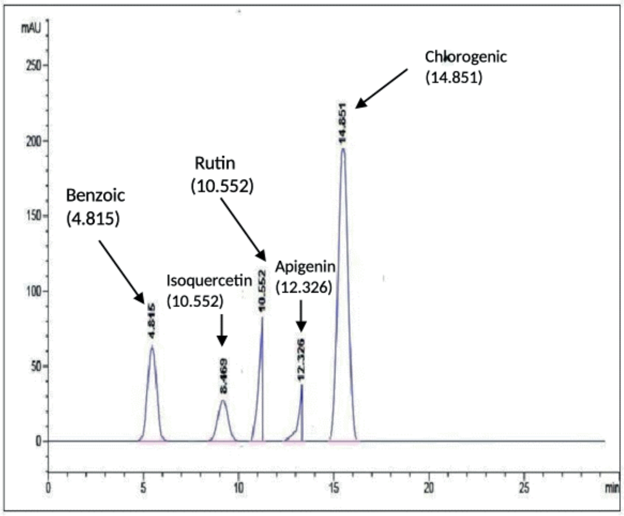

Figure 7. HPLC chromatogram of flavonoids and chlorogenic acid present in the isolated dye of *D. edulis* leaf

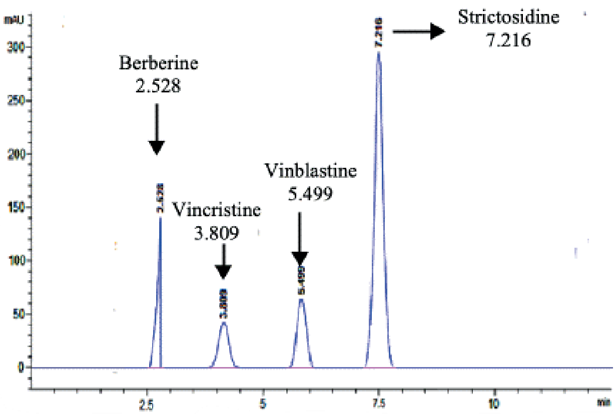

Figure 8. HPLC chromatogram of alkaloids present in the isolated dye of *D. edulis* leaf

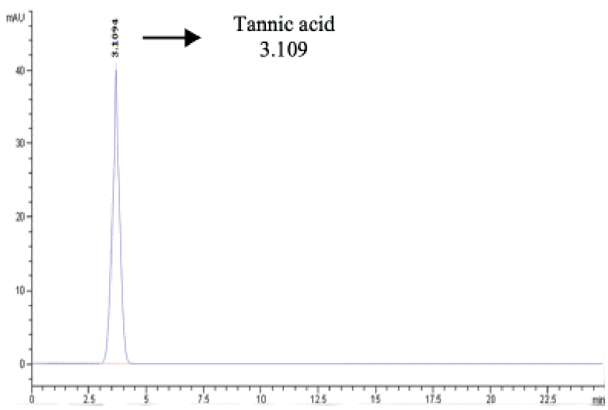

Figure 9. HPLC chromatogram of tannins present in the isolated dye of *D. edulis* leaf

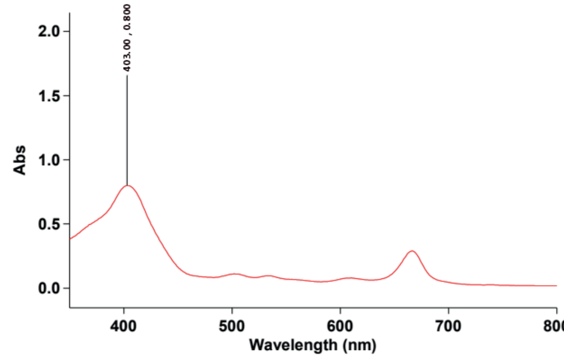

Figure 10. UV-visible spectrum of the isolated dye of *D. edulis* leaf

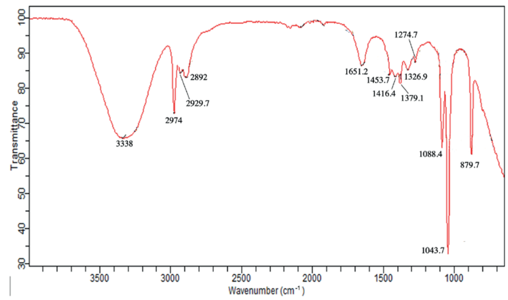

Figure 11. FTIR spectrum of the isolated dye of *D. edulis* leaf

Figure 12. Scanned images of fabrics treated with and without mordant using dyes isolated from *Dacryodes edulis* leaf

3.4 Chemical composition of the colourant

Table 5 and Figure 7 and 13 indicate the identification of four flavonoids (apigenin, rutin, isoquercetin and benzoic acid) and chlorogenic acid present in the dye isolated from the leaves of *D. edulis*. Among these compounds, chlorogenic demonstrated the greatest affinity for the stationary phase, with a retention time of 14.851 minutes and a percentage composition of 39.2. Apigenin exhibited a longer retention time of 12.326 minutes, but a slightly lower percentage composition of 14.2 compared to rutin, which had values of 10.552 minutes and 16.1%. Isoquercetin had a retention time of 8.469 minutes and a lower percentage composition of 12.8 when compared to benzoic acid which had the lowest retention time of 4.815 minutes and a percentage composition 17.7. Table 5 and Figure 8 and 13 present the alkaloids present in the dye. Strictosidine was identified as the most abundant alkaloid, with a percentage composition of 63.6 and a retention time of 7.216 minutes. Vinblastine followed with a percentage composition of 11.3 and a retention time of 5.499 minutes. Vincristine had a percentage composition of 9.04 and a retention time of 3.809 minutes. In contrast, berberine exhibited the shortest retention time and a comparatively high percentage composition among the alkaloids examined, with values of 2.528 minutes and 14.02% respectively. Table 5 and Figure 9 and 13 provide information on the tannin content of the dye. Tannic acid was the only compound detected for tannins, with a retention time of 3.109 minutes and a percentage composition of 100. Tannic acid is an organic compound with astringent properties. It is commonly used in the textile industry to enhance the colour fastness of dyes [30]. Berberine, vincristine and vinblastine are natural compounds derived from plants. Berberine is a traditional yellow natural dye that is biosynthesized from simple, primary metabolites such as acetate, isoprene and amino acids [31]. Vincristine and vinblastine, on the other hand, are native natural products that have been used in traditional medicine and have shown potential in modern medicine as well [32]. Strictosidine holds a significant role in the synthesis of a variety of biologically active compounds [33]. However, it is crucial to emphasize that the findings presented in this study cannot be directly compared to previous literature on *D. edulis* leaf. This is primarily due to the fact that this study represents the first attempt at the preliminary identification and quantification of these compounds. Furthermore, it is essential to acknowledge that retention times may exhibit variation depending on various factors such as solvent composition, extract matrix and the specific gradient elution program used. In previous studies conducted by other researchers, similar findings were reported regarding compounds like rutin, apigenin and benzoic acid. These compounds were identified and quantified through the use of high-performance liquid chromatography (HPLC). Their investigation discovered these compounds to be the principal colourant in their case study [34, 35]. Given the diverse biological properties and different chemical classes to which these compounds belong, they are viewed as a promising option for dyeing materials. Therefore, it is reasonable to suggest that the polar compounds observed in the dye isolated from *D. edulis* leaf may be accountable for its colouring potentials.

The ultraviolet-visible spectroscopy analysis of the dye obtained from *Dacryodes edulis* leaf was conducted within the wavelength range of 400-800 nm as shown in Figure 10. The maximum absorption peak was observed at 403 nm, which aligns with previous research that has established a correlation between the presence of alkaloids, and flavonoids to absorption peaks that range from 234 nm to 676 nm [36, 37]. Alkaloids are known to absorb light in the ultraviolet region of the spectrum of *Physalis minima*, specifically between 234 and 676 nm [36]. Similarly, flavonoids, a group of plant metabolites thought to provide health benefits through cell signaling pathways and antioxidant effects, also exhibit absorption maxima in this range [37]. Therefore, the presence of these secondary metabolites can be inferred from the absorption peak identified in this study within the aforementioned range. This finding supports the notion that *D. edulis* leaf is a rich source of these beneficial compounds.

The spectrum of the dye obtained from *Dacryodes edulis* leaf is in a frequency range of 3500-1000 cm^{-1} (Figure 11). A previous study reported that each spectrum displays a unique absorption band corresponding to a specific chemical composition of the dye [38]. Notably, the dye isolated from *D. edulis* leaf exhibited distinct bands within various segments of the spectrum: 3600-3200 cm^{-1}, 3100-2800 cm^{-1}, 1740-1640 cm^{-1}, 1650-1600 cm^{-1}, 1480-1300 cm^{-1} and 1300-900 cm^{-1}. These bands signify the stretching vibrations of different functional groups, such as O-H, C-H, C-C, C=C, C=O, CHO, aromatics, nitrile and amino acids. Several studies conducted by various researchers have extensively discussed and identified these functional groups corresponding to the various specific segments of the FT-IR spectrum [4, 39-41].

3.5 Colour fastness properties.

The ability of a material to maintain its colour characteristics and prevent the transfer of colour to adjacent white materials when in contact is known as colour fast-

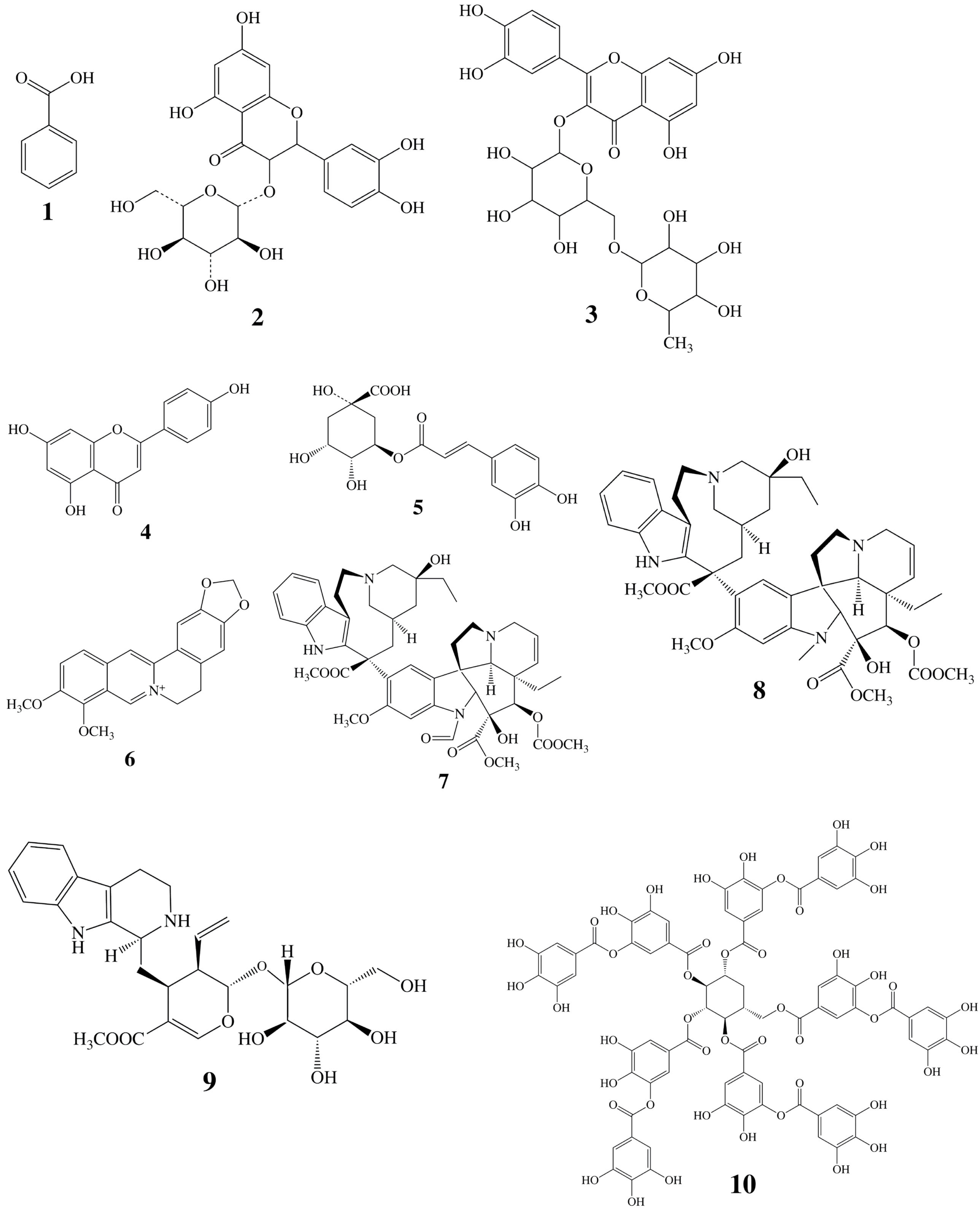

Figure 13. Chemical structures of the constituents of the Isolated Dye from D. edulis Leaf (see Table 5).

ness. Typically, colour fastness is evaluated through the use of a greyscale, either by assessing the loss of colour depth in the original sample or by examining any staining on nearby white material. However, among all types of colour fastness, light fastness and wash fastness are generally considered most important for any textile, while perspiration fastness is particularly relevant for apparel items [42].

3.6 Colour fastness to light

A colour fastness test was conducted on the dyed fabrics to assess their resistance to daylight (Table 6 and Figure 12). The test results showed that the fabric samples denoted as DA 6 % (for wool), DA 4 % and DA 8% (for nylon) on mordanted samples registered a very good rating of 6 on the blue wool scale, while the unmordanted samples had fair to good ratings (3-5). This notable performance is likely due to the colouring component of the dye being an antioxidant, which is known to serve as a UV absorber, thereby enhancing the light fastness of naturally dyed fabrics [43]. These results are consistent with prior studies indicating that the lightfastness of dyed materials is significantly influenced by the characteristics of the compound substituents [44]. Additionally, factors such as symmetry and molecular size can contribute to the high resistance to light. When metal mordants are used, they can form coordination complexes with the functional groups of the natural dyes, further enhancing their light fastness. Moreover, the electronegative oxygen of the hydroxyl (OH) group within the dye structure such as quercetin interacts with the electropositive or cationic hydrogen (H) atom of the -NH-group in nylon 6, which leads to the formation of intermolecular hydrogen bonding between the H atom of the nylon 6 fabric and the electronegative oxygen (O) atom of the colouring compound.

According to research data, a fabric with a blue wool value above 5 is classified as having good resistance to sunlight exposure [45]. Therefore, the deviation observed in the test results for the aforementioned samples could be interpreted as an advantageous characteristic, pointing towards increased durability and longevity of these particular samples.

3.7 Colour fastness to washing

The wash fastness properties of the dyed fabric samples were evaluated and the results are presented in Table 7 and Figure 10. when nylon 6 and wool fabrics were dyed with *D. edulis* leaf, the washing fastness ratings were very good with a rating of 4 at a dye concentration of DA 8 % for both mordanted and unmordanted fabrics. A probable explanation for the good fastness properties is that tannin and flavonoids (isoquercetin and rutin) can form a metal complex with the ferrous sulfate mordant. Hence, after mordanting, the tannin and flavonoids are insoluble in water, thereby ultimately improving the washing fastness. These results suggest that the dyeing process using *D. edulis* leaf extract can be successfully applied to nylon 6 and wool fabrics due to their rich tannin content, which forms hydrogen bonds with carboxyl groups in the protein fibres like wool [46] and with amide group (-NH-) in nylon 6 fibres [47]. On the other hand, the ratings for nylon 6 fabrics, both mordanted and unmordanted showed the lowest rating at 2 and 2-3, for DA 2% and DA 4% respectively, indicating a minimal colour change in the fabrics after washing. This implies that there was a lack of proper fixation of the dye on the nylon fabric, which is a critical step in the dyeing process [48]. Consequently, a larger number of dye molecules were lost during the washing process, leading to a poor rating on the scale.

3.8 Colour fastness to perspiration

The perspiration fastness of nylon and wool fabrics dyed with dye from *D. edulis* leaves were evaluated under acidic and alkali conditions (Table 8 and Figure 12). The fabrics that were mordanted with ferrous sulphate had very good to excellent fastness to alkali perspiration at 8% dye concentrations for both nylon and wool with a rating of 4-5. The fabrics also showed excellent fastness to acidic perspiration at 8% dye concentrations with a rating of 4-5 for mordanted fabric and good fastness to perspiration for unmordanted fabric with a rating value of 3. These results indicated that *D. edulis* dye is not only resistant to alkali perspiration but also to acidic perspiration. These results indicate that the alkali and acidic extract of *D. edulis* dye can produce fabrics that are resistant to perspiration in different environments. Furthermore, recent research by Prabhavathi et al. [49] supports the effectiveness of ferrous sulfate as a mordant in enhancing the perspiration fastness of natural dyes on textile materials.

3.9 Colour fastness to rubbing

The rubbing fastness results for nylon and wool at dye concentrations ranging from DA 2% to DA 8 % are presented in Table 9 and Figure 12. Comparatively, it is evident from the results that the dry rubbing performance for mordanted and unmordanted fabrics was superior to their wet rubbing performance for both wool and nylon 6, being rated as poor to very good (1-4). The difference in diffusion behavior between dyes with varying molecular weights and structures can be attributed to the low aqueous solubility of ferric-tannate complexes within the dyed fiber. When large molecular size complexes form in the dyeing bath, they have a very low diffusional behavior. As a result, these complexes primarily deposit on the periphery of the dyed fiber, leading to a low wet rubbing fastness. This phenomenon has been studied by Mongkholrattanasit et al. [48], whose research supports the idea that the diffusion behavior of these complexes is significantly influenced by their size and solubility characteristics. Further research indicates that dyes with larger molecular weights and intricate structures such as red 195, exhibit slower adsorption rates compared to those with lower molecular weights like blue 19 [50] affecting their diffusion dynamics during the dyeing process.

3.10 Colour measurement

The changes in K/S values of samples mordanted and unmordanted at various concentrations are shown in Table 10. The study found that the K/S values increased as the concentration of the mordants increased. This is in line with the results of the mordanted and mordanted samples, which showed deeper shades than those of the unmordanted samples. Additionally, the L values also decreased as the concentration of the mordant increased.

4. CONCLUSION

The study successfully extracted natural dyes from *Dacryodes edulis* and characterized the resulting dyes using various analytical techniques. It highlighted the significance of understanding the chemical composition and structure of these natural colourants, through methods such as UV-Vis spectrophotometry, high-performance liquid chromatography (HPLC) and Fourier-transform infrared spectroscopy (FTIR). The extraction process was optimized to obtain high-quality colourant using ethanol at the optimal conditions of 65.9 °C for 2 hours. These findings provide valuable insights into the potential application of these natural colourants, particularly in textile fabrics like nylon 6 and wool. The isolated dye exhibited promising results, especially in terms of colour fastness to light ranging from moderate to very good, with a rating of 4-6 on the scale and somewhat fair to excellent levels of perspiration in both alkali and acidic conditions with a rating of 2-5. This study successfully demonstrated that the leaves of *Dacryodes edulis* can be effectively utilized for extracting a natural dye, presenting a sustainable solution with minimal negative environmental impact. This information is important for textile manufacturers seeking to adopt sustainable practices and reduce their reliance on synthetic dyes.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest regarding the publication of this manuscript.

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Feature Articles

Perception of Chemistry and Chemistry Education: a Case Study and Some Reflections

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Abstract. Perception of chemistry in the general public has been object of several investigations in the past, putting in evidence the diffusion of neutral or negative attitudes, which can be summarized in the so-called 'chemophobic' behaviour. In the present study we analysed the results obtained from a structured survey aimed to intercept Italian young people and to investigate the relationships among their chemistry perception, school experiences and chemistry background. The complete questionnaire was made of 29 questions (25 multiple choice questions and 4 open questions) and the analysis of results was performed on 431 participants, which were selected among initial 627 ones to exclude chemists or students in chemistry. The investigated sample gives a snapshot of Italian young people of medium-high school education, and it reveals a general not-negative perception of chemistry, but a relatively low engagement toward chemistry-related subjects. Interestingly, most people are aware of the role of chemistry teachers and school experiences in their attitude toward chemistry and, at the same time, the participants to the survey demonstrated to have a relatively poor knowledge of the main concepts of chemical science. These aspects may be helpful for chemistry educators at different levels, from primary schools to the universities.

Keywords: image of chemistry; image of science; perception of chemistry; chemistry knowledge; communication of chemistry; chemistry education.

1. INTRODUCTION

Chemistry is one of the most important branches of science since the knowledge of basic concepts of chemistry is as essential for further studies in chemistry-related fields as well as for approaching other sciences, such as natural science, biology, biochemistry, physics, environmental sciences and geology.[1] Most importantly, it enables learners to understand what is happening in the World around them and to use a scientifically critical approach to evaluate and assess the information about different topics related to chemistry that they may encounter every day in newspapers, television programs or in the context of a conversation. Moreover, a good knowledge of chemistry can help people to debunk conspiracy theories and other counterproductive scaremongering attitudes, as those referred as 'fake news'.[2] Despite its importance in daily life, chemistry is often considered a difficult subject by those ones who approach this science as beginners.[3,4] Is this merely a prejudice or is there a reason behind this mistrust towards chemistry? Why is it considered such a challenging field of study? Nowadays, the bulk of the population has a fairly sceptical attitude towards science in general.[2,3] This does not refer to the scientific kind of scepticism, which is based on enquiry, empirical research and reproducibility of results, but a general mistrust of the solutions offered by science, giving chemicals a reputation as 'unnatural', 'artificial' or 'poisonous'.[2,5,6] In the marketing world this tendency is exploited to improve the sales of so-called 'natural' products.[6] Another term which is often used by organic companies is 'chemical-free', an extremely misleading claim which rings absurd for any professional scientist, if not for others. The word 'natural' is often used to imply 'healthier' and 'safer'. This is misleading because many natural substances are neither healthy nor safe (e.g. nicotine or arsenic). Chemical scientists use 'natural' to describe substances that are derived from Nature. The word 'synthetic' is sometimes used to mean 'unpleasant' or 'dangerous', however, it simply means 'man-made'. A similar word, 'artificial', implies, in addition, that a chemical does not occur naturally, whereas 'synthetic' may refer to naturally occurring chemicals that are copied by humans with industrial or laboratorial processes.[2,7] Another misused word is 'contamination', which is frequently used to imply harmful effects.[8] However, just because a substance is found somewhere it does not normally occur, this does not necessarily mean it is having a detrimental effect. Making the public aware of how words are misused by the media is a very powerful tool in the fight against scientific misinformation and it is necessary to improve the way chemistry is seen by the public.[9]

In their article, "Communicating Chemistry for Public Engagement", Matthew Hartings and Declan Fahy[10] affirm that chemistry's bad reputation is due to 'chemophobia', a word invented by Pierre Laszlo, who is both a chemist and a populariser of science, to describe the evident trend in the words that people associate with chemistry, such as "poisons, toxins, chemical warfare, alchemy, sorcery, pollution, and mad scientists".[11] One of the consequences of chemophobia is that people working in creative fields, such as television, cinema or publishing, avoid associating the word 'chemistry' with the title of their products, fearing that consumers will keep their distance due to bad hangovers from school days or a fear of chemicals.[2,7]

Chemophobia has several definitions, such as: "an irrational aversion to or prejudice against chemicals or chemistry", "more specifically it refers to the growing tendency for the public to be suspicious and critical of the presence of any man-made (synthetic) chemicals in foods or products that they make use of".[2,7,12-15] This social phenomenon has been linked both to a "well-founded concern over the potential adverse effects of synthetic chemicals", and to "an irrational fear of these substances because of misconceptions about their potential for harm".[16] Different organizations define the word chemophobia in different ways. The IUPAC (International Union of Pure and Applied Chemistry) describes chemophobia as an "irrational fear of chemicals".[17] For the American Council on Science and Health, chemophobia is a fear of synthetic substances arising from "scare stories" and exaggerating claims about their dangers prevalent in the media.[17] Chemistry professor Pierre Laszlo, who is famous for his work on scientific popularization, writes that historically, chemists have experienced chemophobia from the majority of the population, and he "considers it to be rooted both in irrational notions and in genuine concerns (such as those over chemical warfare and industrial disasters)".[11] Chemists made a great deal of effort to counteract chemophobia,[18,19] particularly with regard to educating consumers on the safety of food additives and prepackaged foods.[15] Other counteractions, such as improved communication of science[10,14] or strategies for tackling adult chemophobia, are described in the literature. Many different organisations also tried to fight this attitude and restore a positive image to chemistry. In the United Kingdom, several associations, such as the Royal Society of Chemistry (RSC),[20] and in Italy, the *Società Chimica Italiana*,[21] are working to debunk misconceptions and other counterproductive attitudes towards chemical issues. A very significant action was carried on by the Royal Society of Chemistry in 2015, when a deep investigation about the perception of chemistry in UK[22] was performed. This was the first national, in-depth study on how the UK public thinks and feels about chemistry, chemists and chemicals. The aim of this study for the chemists of RSC was to achieve a better understanding of how chemistry is perceived by the general public. A result that came as quite the surprise to professional chemists is that, on the whole, the public has a much better opinion of chemistry, chemists and chemicals than was expected. People also recognize the positive contributions of chemistry both to their daily life and to economic growth and are fairly certain that the benefits of chemistry far outweigh any harmful effects.[22] Based on this study, the Royal Society of Chemistry released a communication toolkit.[23] Taking the key findings of the study as a springboard, the guidelines of this toolkit were written to help professional chemists to communicate more efficiently in various contexts with their public. The study showed a fairly widespread feeling of ambivalence towards chemistry that causes a lack of both engagement and understanding of chemistry. Although people recognize its positive role in the betterment of society, chemistry is still considered a difficult and, frankly, dry subject to study.

The guidelines suggested by the RSC[23] were designed to cover the weak spot of the public attitude towards chemistry, especially the lack of emotional connection and the lack of confidence found in the public. To establish a personal link with chemistry, professional chemists should let their passion for chemistry shine through when they discuss it. According to these documents,[22,23] the enthusiasm perceived by the public could help them to relate more positively to chemistry, viewing chemists as individuals with passions and interests rather than the cold, detached image of a scientist, thereby helping to build a feeling of familiarity.

An interesting work concerning the public perception of chemistry in the general public was published by Guerris *et al.* in 2020.[9] This study was based on the analysis of more than 200 thousand tweets on the social network 'Twitter', containing the words "chemistry", "chemical" or "chem". From this study[9] the authors reported a prevalence of topics related to the learning environment, activities and tasks in chemistry courses, and human activities related to chemical industry. Interestingly these short messages contained more positive than negative perceptions of chemistry. However, chemophobia-related terms were present in large amount.

In the Italian context, the image of chemistry was first investigated in 2005-2006 on a selected sample in the context of science museums and, in particular, of museums of chemistry,[24,25] revealing a relatively low impact of these contexts in the general public, mainly due to several limitations of these non-formal contexts (i.e. low number of visitors, lack of funding, …). On the other hand, the strong relationship among these science museums and schools, from primary schools to the universities, has been often demonstrated to be effective in rising the engagement of people toward chemistry, to change the visitors' perception, and to get better the learning and teaching of chemistry.[25-29]

In the present paper, we report the complete results of the analysis of an on-line survey which was designed to investigate the perception of chemistry among young Italian people and to explore the relationship of the image of chemistry with previous school experiences and chemistry knowledge. Preliminary and partial results were published in the Italian journal '*La Chimica nella Scuola*'.[30] The results of this survey are interesting since they indicate a correlation between the image of chemistry of the participants and their previous school experiences, as well as to their knowledge about basic principles of Chemistry.

2. MATERIALS AND METHODS

2.1 The structure of the survey

The survey was structured into three parts: the first is concerned with the personal details of the subject (6 questions); the second is about the perception and image of chemistry (15 questions); the third is about the subject's chemical knowledge and awareness (8 questions). The complete questionnaire made of 29 questions (25 multiple choice questions and 4 open questions) can be found in the Appendix A.

First part. The personal information and requested details are age, gender, educational history and current occupation. The study specifically targeted young people (for our purposes, 18-40 years of age). Also, the questions about the subject's chosen educational field help to characterize the survey population, giving a full and rounded picture of the target audience at hand. Of particular interest is secondary education specialization, that is to say which type of school the subject chose, be it an academic secondary school (scientific or humanistic high school), or a technical / professional school, as well as the prevalent subjects taught, such as sciences, art, humanities, economics, technology etc. Further on, the test subjects are asked to specify their choice of university course. Finally, the survey asks about their current occupational status (student, employed, unemployed). These pieces of information are essential to create a faithful image of the test population and to analyse the data collected coherently.

Second part. The second part of the test focuses on the perception and image of chemistry. It seeks to investigate specifically what people associate with chemistry, how they feel about it and how important they consider its role in daily life. Further questions deal with their relationship with chemistry as a school subject, the problems encountered when they studied it and the role of the teachers. People are asked to state how confident they feel about discussing a chemistry-related topic, which applications of chemistry interest them and where they normally encounter chemistry-related topics. A few of these questions were inspired by those in the study released in early June 2015 in the UK by the Royal Society of Chemistry.[22]

Third part. In the third part of the test, knowledge of chemistry is assessed. The questions are about simple general chemistry topics and are related to their applications in daily life. People are asked to assess their own scientific knowledge, e.g. the definition of a scientific theory, the differentiation of physical from chemical changes, identifying the right molecular representation of a simple reaction, separating substances from mixtures of substances and finally, calculating the concentration of a solution. The final section examines popular attitudes towards the presence of chemicals in everyday life.

2.2 The participants

The survey was published on-line, and it was spread through social networks, such as Facebook, Twitter and YouTube.[30,31] In about two months, 627 people answered to the survey. For the analysis of data, people who was studying or studied chemistry or chemistry-related subjects (such as pharmacology or pharmaceutical chemistry) have been excluded from the survey population in order not to skew the results of the study. After removing those test subjects, the overall sample size is 431 participants.

2.3 The analysis of the survey

The survey was built on a google form so that the statistical analysis could be performed simply by using Excel. Further elaborations of the collected information were performed with free visualization tools, such as Voyant tools.

3. RESULTS

3.1 An overview of the personal information data

The personal information data collected conveys the image of a very young population (Figure 1a): around 82% are under 30 years old and 50% are between 18 and 24 years old. Therefore, the age range that we wanted to target specifically has responded satisfactorily and we are able to draw conclusions applicable to the Italian youth.

As far as the highest level of education completed goes, about half the subjects (51%) only finished their secondary education and 27% finished their undergraduate studies. The rest of the population sample obtained a postgraduate degree or a PhD (Figure 1b). However, this suggests that our sample cannot be considered representative of the average Italians, as other statistics show that in Italy a not insignificant number of students leave the high school before completion. The majority of people who took the test were still studying during the survey (Figure 1c): 68% are students, working students or PhD students, revealing a population which is still largely in education, thereby providing us with a fairly representative picture of the Italian school system.

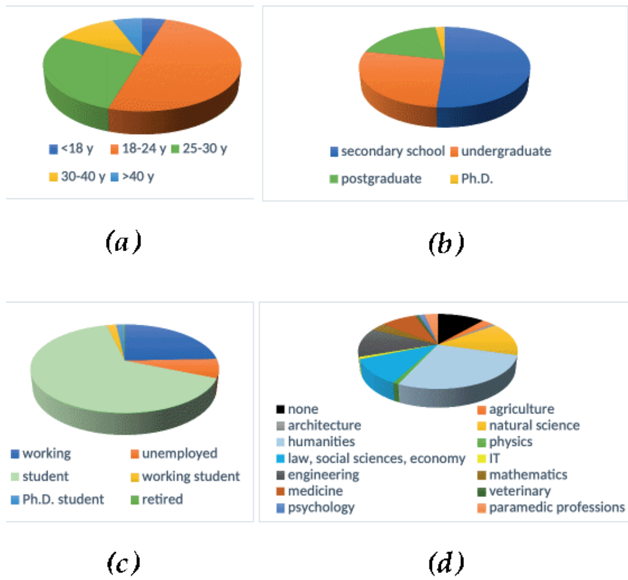


Figure 1. (a) Age distribution of the population sample; (b) Highest level of education completed at the moment of the survey; (c) Current occupation; (d) Area of University study. Note that 'IT' stays for 'Information Technology'.

Moreover, 58% of the population attended a scientific lyceum or scientific technical school at secondary level. About 36% had a humanistic education (classic, linguistic or socio-pedagogic ones). Other areas of educational paths, such as economy, hospitality and professional ones, are underrepresented.

A relatively low percentage of 11% never attended the University, suggesting a broadly well-educated sample compared to the national average. Around 48% of the sample studied or is studying a science-related subject, indicating that they (most probably) studied chemistry up to university level and therefore should have an in-depth knowledge of the relatively elementary topics tested later in the study (Figure 1d).

The last question of this first part of the test concerned the gender distribution of the population: it emerged that 67% of the people participating in the study were female, indicating a distinct gender bias.

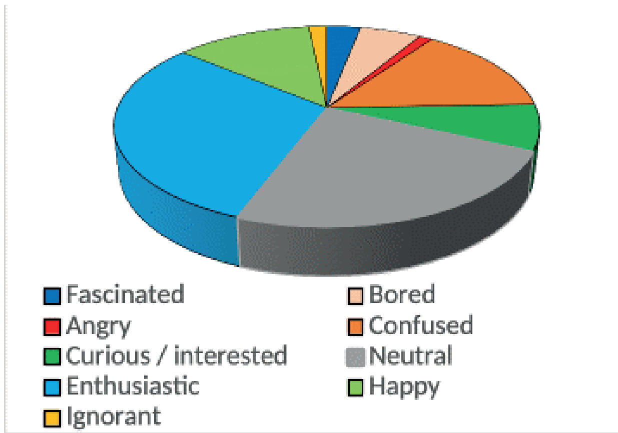
3.2 An overview of the public attitude towards chemistry

The second part of the test is about the public attitude towards chemistry of the population sample. The first question was an open question asking what people associate with the word ‘chemistry’. This question was intended to collect ideas, impressions and thoughts as in a brainstorming activity. By using the Voyant tool a “word cloud” was generated from the text provided, giving more importance and therefore more space to the words that appear more often in the text.[30]

Recurrent words include ‘chemical’, ‘periodic table’, ‘elements’, ‘matter’, ‘laboratory’, ‘school’ and ‘life’. This trend denotes that most people relate chemistry to memories of the subject as taught at school and it may have trouble shaking off its scholarly image to graduate into real-life. Maybe surprisingly for some chemists, one of the most commonly used words is not ‘poisonous’, ‘harmful’ or ‘artificial’, but ‘life’, a very positive term which connects chemistry with the vital experience and recognizes chemistry as essential for life. Other words which frequently recur reinforce this idea: ‘everything’, ‘world’, ‘food’, ‘interesting’, ‘good’, and so on. One collocation with a moderate recurrence rate is “Breaking Bad”, a clear reference to the American television series, which is quite popular among young people in Italy, too. This fact indicates how the media can deeply affect the public’s perceptions and way of thinking. Other recurring words include ‘biology’, ‘medicine’, ‘organic’, ‘inorganic’, ‘cosmetics’, ‘physics’, ‘research’, ‘complex’ and ‘science’: this choice indicates that people are aware of the centrality of chemistry in relation to other sciences and its importance in the process of reaching the modern standard of living we are used to.

Afterwards, the subjects were asked how they feel about chemistry. Positively, over 30% feel enthusiastic about it (see Figure 2a). Another key result is that 24% of the population feel neutral about chemistry. A similar trend (but even more emphasized) of neutrality was found in the UK study.[22] Almost 15% of the population assert that they feel confused about it, revealing that chemistry is still regarded as a difficult and puzzling subject to study by a significant part of the population, and this may contribute to and even perpetuate the image of chemistry and chemists as fairly insular.

As shown in Figure 2b, another important result is that people consider chemistry essential to our modern way of life: over 68% of the population deem chemistry to be necessary in daily life. Many chemists often feel that the subject to which they dedicated their life is underappreciated or underestimated by the general public,[2,5,7] but this result reveals that the public has a better perception of chemistry than most professional chemists would have guessed. This disparity may represent a generational gap. Those who grew up with a fear of the unknown and the possibilities of chemical warfare may reflect such insecurities onto a younger generation who, in reality, are much better informed and more comfortable with the role of chemistry in daily life, aware that the chemist no longer represents the warmonger, but rather a key part of the production of everything around them.



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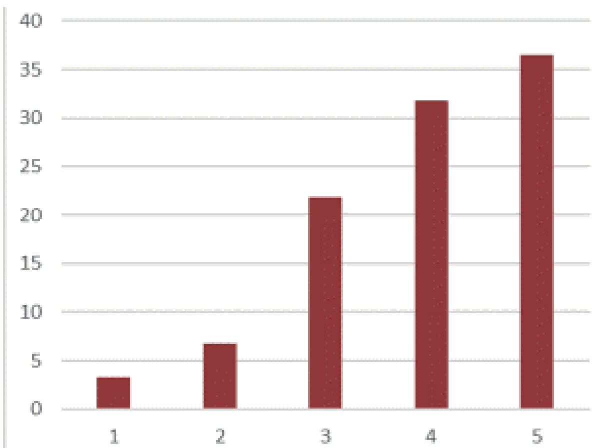
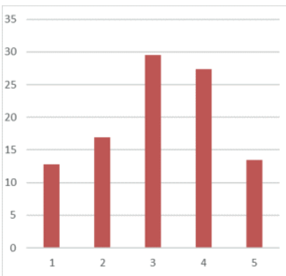
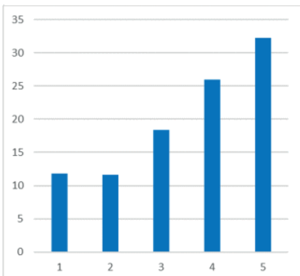


b)

Figure 2. (a) Answers to the question ‘How do you feel about chemistry?’ (b) Distribution of answers, expressed as percentage values, to the question ‘How important is chemistry in daily life?’ 1 is for ‘Un-necessary’ and 5 is for ‘Necessary’.

In this section we are reporting the results of the survey concerning the participants’ previous school experiences with the subject of 'chemistry'. This aspect is important to understand what the role of school is, and, in particular, the influence of chemistry teachers in the perception of chemistry. From the survey, we see that around 30% of the sample had an awful experience with chemistry at school, another 29% had a neutral one and 41% had a good or very good one (see Figure 3a). Another relevant, yet unsurprising, result is that 58% of the population consider the role of the teacher important or very important in learning and studying chemistry (see Figure 3b). This attitude shows the importance of the teacher's education and training as well as his/her teaching skills. To enhance the perception and the knowledge of chemistry among the public, it is essential to keep the teachers up to date with the progress made both in chemistry and in the educational sciences. These results are in line with previous findings based on chemistry teacher training experiences.[24-28]





(a) *(b)*

Figure 3. (a) Distribution of answers, expressed as percentage values, to the question 'How would you describe your relationship with the study of chemistry?' 1 is for 'awful' and 5 is for 'very good'. (b) Distribution of answers, expressed as percentage values, the question 'How important has been the role of the teacher in learning and studying chemistry?' 1 is for 'Not important' and 5 is for 'Very important'.

When asked about the problems they encountered while studying chemistry at school, people gave results which provided an interesting insight into the priorities of the Italian educational system (see Figure 4).

Almost a third (32%) agree that there is not enough emphasis on the applications of chemistry in day-today life. This finding is particularly relevant for educators, because it suggests to them which path can be followed in order to improve their students' engagement with chemistry as it is taught at school, which, as we have seen, is vital in shaping their lifelong relationship with the science. About 24% selected the answer 'Not enough study and practice', putting in evidence the few hours dedicated to the subject of chemistry, especially in some high schools, and the lack of laboratorial activities and practice. Another result to be taken into consideration for a overall approach to education is that 19% consider their mathematical skill too poor to facilitate a good understanding of chemistry (see Figure 4). This result suggests that educators should make it a priority to verify that the mathematical skills of their students are adequate for the topics they want to cover in chemistry lessons: for example, a poor knowledge of the meaning and implications of the logarithmic function can greatly affect the understanding of pH in chemistry. The problem with abstract concepts, reported by 18% of the public, is well documented in the literature and confirms that the difficulty (confirmed by 16% of the public) of chemistry lies in its highly conceptual nature.[4] A significant 43% of the population relate the problems they encountered with the study of chemistry with more general failings in their approach to their studies, such as poor study skills or not enough practice and study. Also, a lack of interest and motivation, reported by 16% of the public, gravely affects the learning of this school subject.

When questioned about the preparation of chemistry teachers, around 48% consider the teachers well or very well prepared, 24% neither well nor poorly prepared and 28% of the population think that their teachers are not knowledgeable enough (Figure 5a). Some constantly recurring comments written in the free comment area bemoaned the lack of adequate funding dedicated to laboratory work, school syllabi which seem out of date and the large presence of chemistry teachers in secondary schools who trained at the University mainly in biology or natural sciences, rendering them unprepared for the broad range of enquiries that a curious student mind can bring to the table.

The question summarized in Figure 5b deals with the confidence that people have when discussing chemistry-related topics. The unsurprising result is that only 23% feel confident enough, while 48% don't feel up to confidently talking about a chemistry-related topic and the remaining 30% neither agree nor disagree. This could suggest that whilst a superficial knowledge of some other topics tends to suffice for the purposes of a casual conversation, chemistry is viewed as a more technically in-depth subject which requires comprehension of various aspects for even a low-level discussion.

When questioned about where people encounter chemistry-related topics (see Figure 6a), a surprising 54% talk about it with other people, including friends, family members and colleagues. Social networks and television programs were confirmed to be the most widely used media in modern society, garnering a frequency of 37% and 45% respectively. As previously mentioned, a very

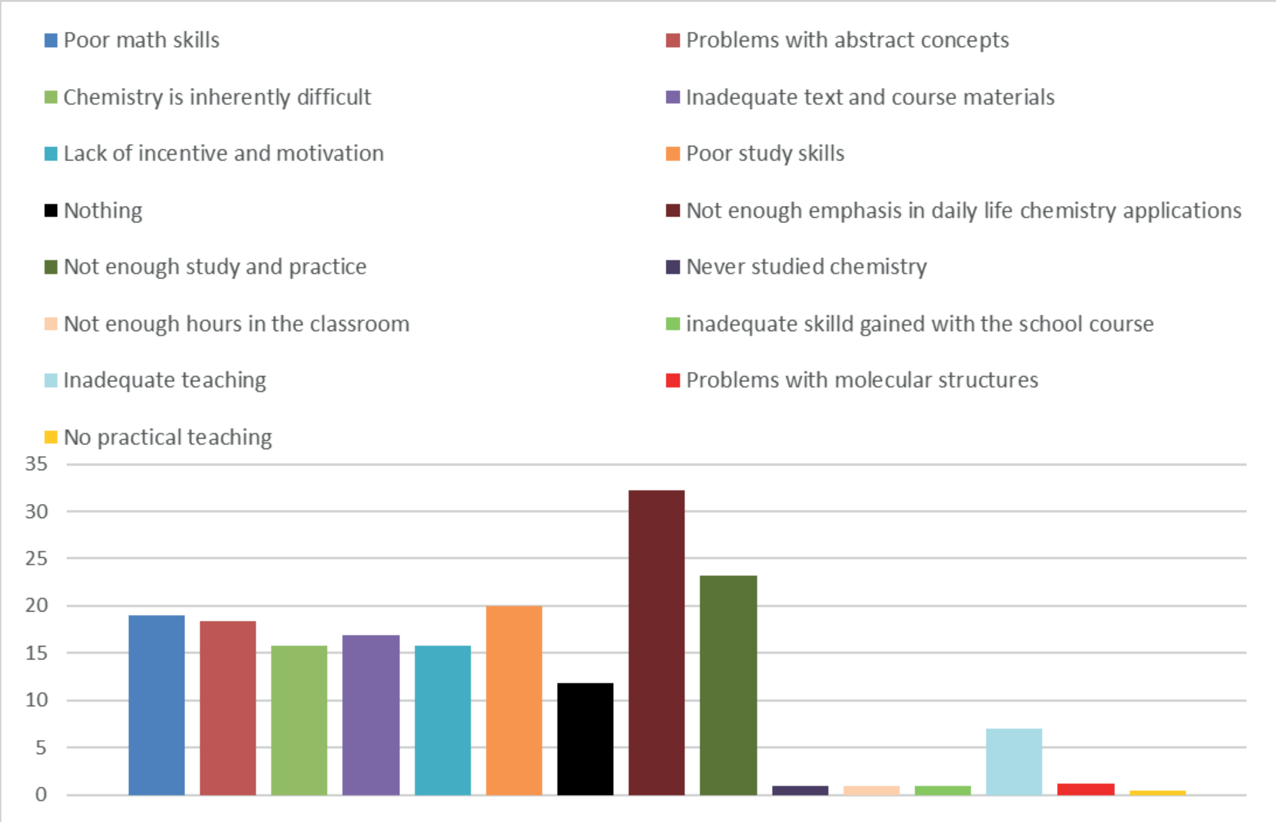
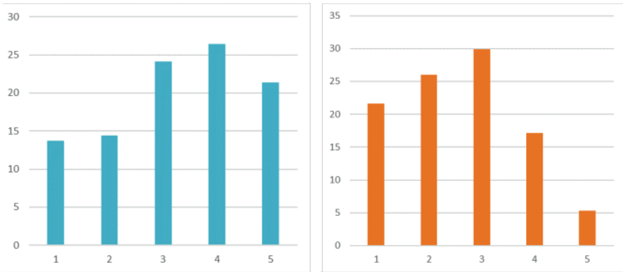


Figure 4. Distribution of answers, expressed as percentage values, to the question 'What kinds of problems have you encountered when studying?' People could select among a series of answers and they could select more than one choice.

important role is also played by television series: 35% of the population encounter topics connected with chemistry thanks to TV series such as "Breaking Bad". 20% find topics connected with chemistry on YouTube, 34% in books and 36% in scientific journals.

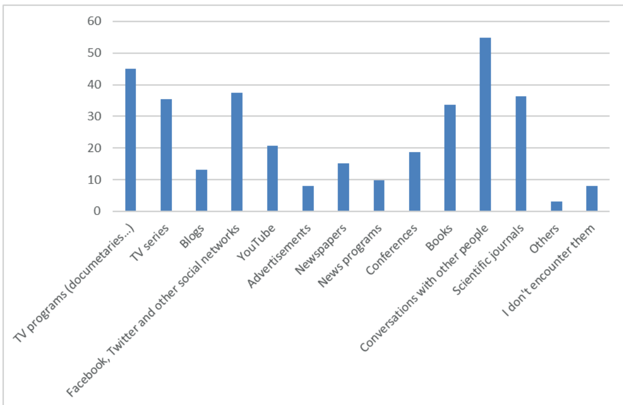
One of the most important results of the whole study relates to the applications of chemistry that people are most interested in as reported in Figure 6b: 53% are interested in medical chemistry, 42% in environmental chemistry and 39% in food chemistry. These particularly encouraging results reveal that people do not fail to grasp the importance of chemistry for the progress of mankind and they do not only relate it to disasters of the past such as the thalidomide scandals in pharmacology or environmental disasters such as the Bhopal methyl isocyanate gas leak. This attitude shows that people are able to see both the positive side of science and its risks, whilst still believing in the importance of scientific process.

In the next question, people were asked what could be done to improve the image of chemistry (see Figure 7). One of the results was especially striking: 77% of those surveyed think that more lesson time should be devoted to the everyday applications of chemistry. The necessity for more emphasis on everyday applications came out in other test questions previously discussed here. This result should be taken into consideration by educators as it reveals that people would be more engaged with science if they were taught about the many essential and interesting applications it has in everyday life. Another 61% would like more effective collaboration on the part of scientists, both in exposing the general public to chemistry and in providing clearer explanations when discussing the subject, using layman's terms where possible. Chemists and science popularisers are asked to improve their communication skills in order to make chemistry more appealing to the public. This is an important feature underlined in the last two decades by chemists too.[3,10,14]



(a) *(b)*

Figure 5. (a) Distribution of answers, expressed as percentage values, to the question 'How prepared were your chemistry teachers?' 1 is for 'very poorly' and 5 is for 'very well'. (b) Distribution of answers, expressed as percentage values, to the question 'I feel confident to talk about chemistry' 1 is for 'strong disagree' and 5 is for 'totally agree'.



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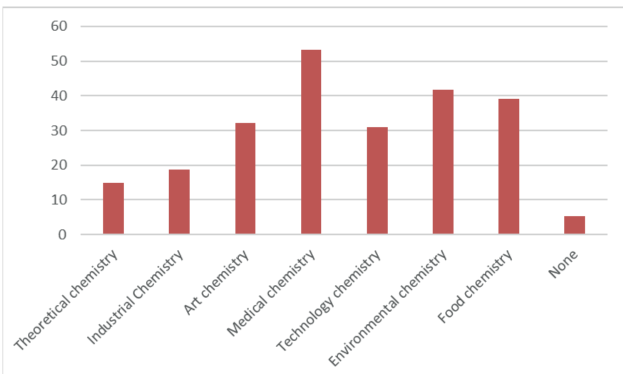


b)

Figure 6. (a) Distribution of answers, expressed as percentage values, to the question 'Where do you encounter topics connected with Chemistry?' People could select among a series of answers and they could select more than one choice. (b) Distribution of answers, expressed as percentage values, to the question 'Which application of Chemistry are you interested to study further?' People could select among a series of answers and they could select more than one choice.

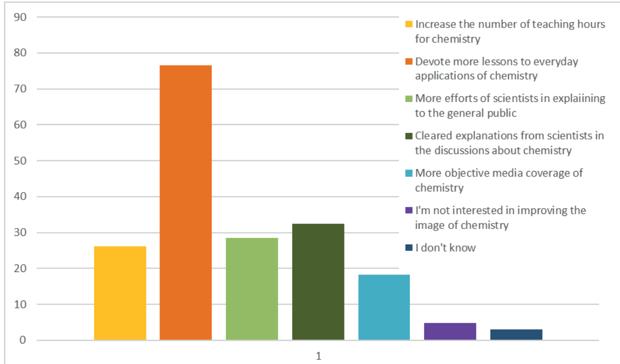


Figure 7. Distribution of answers, expressed as percentage values, to the question 'What could be done to improve the image of chemistry?' People could select among a series of answers and they could select more than one choice.

In the last question of this section, people were asked whether they ever visited a chemical-related factory (Figure 8). The fact that 72% had never visited one reaffirms the lack of experience of everyday applications of chemistry and shows how important it is that schools provide such a formative and informative experience for their students. The chance to see a chemical process with their own eyes can help people to address possible misconceptions that they might have and evaluate chemistry in a fairer way. Moreover, as reported in a recent work,[32] chemical industries have a role in the building of chemophobic attitudes and in the diffusion of erroneous ideas about chemistry. In this respect, the direct knowledge of industrial sites through open-days and other initiatives could be of help in counteracting the chemophobia.

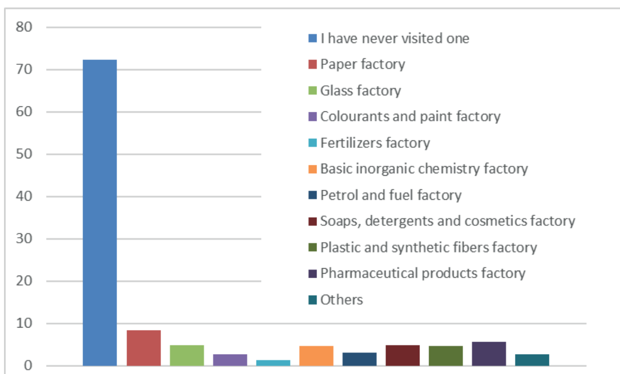
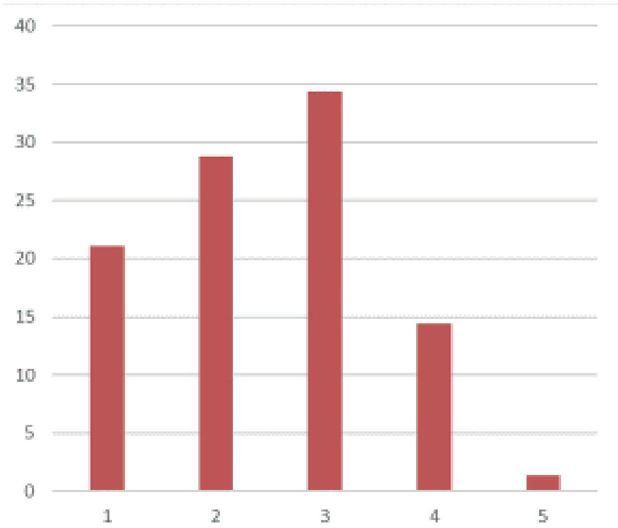


Figure 8. Distribution of answers, expressed as percentage values, to the question 'Have you ever visited a chemical-related factory?' People could select among a series of answers and they could select more than one choice.

3.3 An overview of scientific-chemical knowledge

In the third part of the survey, the questions were more focused on the assessment of the chemical knowledge of the participants. Specifically, the first question was a self-assessment in which people had to evaluate their own knowledge of chemistry (Figure 9a). Around 50% of the sample deem their knowledge to be poor or very poor. Another 34% consider it neither good nor poor and only 16% think they have a good command of chemical knowledge.



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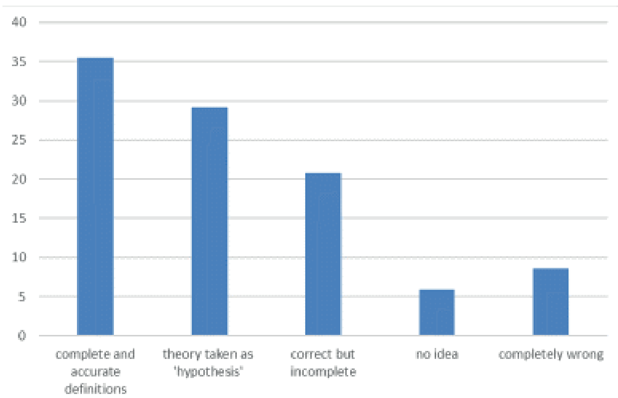

b)

Figure 9. (a) Distribution of answers, expressed as percentage values, to the question 'How do you perceive your knowledge of chemistry?' 1 is for 'completely inadequate' and 5 is for 'very good'. (b) Distribution of answers, expressed as percentage values, concerning the participants' definition of what a scientific theory is'.

The following question asked people to give the definition of a scientific theory. The choice of introducing this open question is related to the diffusion of fake news and the spread practice to confuse scientific and pseudoscientific news.[2] A selection of representative definitions given by the participants is: [A scientific theory is] 'an hypothesis that is confirmed by an experiment', 'a statement used to explain a phenomenon', 'an assessment that need to be demonstrated', 'an hypothesis about a phenomenon that is not yet falsified', 'an opinion on a phenomenon that is based on scientific data which confirm it', 'a product of a thinking process which is based on the scientific method', 'an hypothesis that can be validated by experiments and scientific evidences'. Overall, 55% gave an almost correct definition, but 21% were not precise enough in the explanation, leaving an incomplete or vague answer. As seen from this selection of definition, a large part of the sample (about 29%) took "theory" to mean "hypothesis" in the context of scientific method; this result is particularly relevant for two distinct reasons. Firstly, a significant part of the population lacks understanding of the scientific method, which is the foundation for any scientific subject. The second and most disconcerting reason is that they literally mistake a scientific theory, which is the most reliable, rigorous, and comprehensive form of scientific knowledge, for a mere "hypothesis". This misunderstanding may lead to a situation where many people say "evolution is just a theory" assuming that this means its basic principles are still debatable. They do not realize that gravity is also "just a theory," and that, to a scientist, a theory is an explanation of what has been observed.

The following questions are related to fundamental concepts in chemistry. For instance, a question aims to assess the participants' knowledge of what a chemical reaction is, and if they are able to identify chemical reactions among a series of processes. The results showed in Figure 10a indicate that a large part of the population has problems distinguishing a chemical reaction from a physical transformation: 55% considered the solution of sugar in water to be a chemical reaction when it is in fact a special kind of mixture between two substances. 27% and 29% respectively took evaporation of water and dilution of fruit juice concentrate to be chemical reactions. These results show that a fairly large proportion of the population lacks some basic knowledge of chemistry on topics that are normally explained within the first weeks of secondary school and that are necessary for further understanding of the subject. These results agree with several works reported in the literature showing the diffusion of misconceptions among first year undergraduate students.[33]

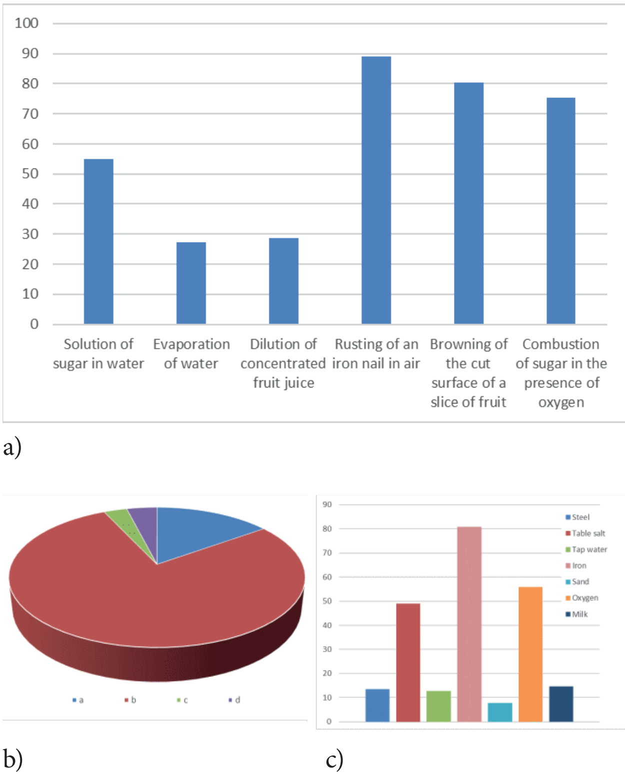

Figure 10. (a) Distribution of answers, expressed as percentage values, to the question 'Which ones are chemical reactions?' The right answers are the 4th, 5th and 6th, while the 1st, 2nd and 3rd were wrong answer. (b) Distribution of answer, expressed as percentage values, related to the correct graphic representation of the chemical reaction of hydrogen and nitrogen to give ammonia (see question 24 in the Appendix A). The correct answer is 'b'. (c) Distribution of answer, expressed as percentage values, concerning the question: 'Which are substances and not mixtures of substances?' People could select more than one option.

Another important ability to assess is related to the understanding of the correct link between a chemical formula (with its element symbols) and its graphical representation (referring to a simple particulate model of matter). Given a specific chemical equation which was already balanced, in our case the formation of ammonia (see question n. 24 in Appendix A), people had to identify the molecular representation that most accurately portrays the chemical reaction. This question was also designed to evaluate the ability to pass from a symbolic level to a representational one. Overall, 78% gave the correct answer ('b'), proving that they were able to link symbolism with representation, often considered a particularly difficult skill to acquire for novices (Figure 10b).

Another key concept in chemistry is that of 'chemical substance'. When asked to determine which are substances and which are mixtures of substances among a series of options, more doubtful results arose, as people often failed to distinguish one from another. As shown in Figure 10c, 81% consider iron a substance (correct answer), but only 56% gave the same answer for oxygen and only 49% for common table salt. A surprising 15% consider milk to be a substance and not a mixture. Sand and tap water are mixtures, too.

In the next question, participants were asked to solve the following problem about dilution: "A 330 mL can of Coca-Cola contains 36.3g of sugar while 100 mL of ACE juice contains 12.1 g of sugar. Millilitre per millilitre, which one contains more sugar?". As seen in Figure 11a, only 56% gave the right answer to this question, yet the solution required only simple mathematical skill, normally acquired around age 11.

After posing the sorts of questions that participants may have encountered at school, the attitude of the public towards chemicals was investigated. Three different statements about chemicals were presented and people had to agree or disagree with what was said on a scale of 1 to 5 (see Figure 11b). These results are quite encouraging as far as questions about the negative image of chemistry and of chemicals: 89% of the population agreed that everything is made of chemicals.

The final two questions are related to some diffuse misconceptions: the fact that natural substances are all not-toxic and in general safe, and that chemicals are a product of man activities. As seen in Figure 11c, 69% of the population agreed that everything, including water and oxygen, can be toxic at a certain dose, and 92% of the total sample disagreed that all chemicals are 'man-made', as shown in Figure 11d.

These findings relating to the perception of chemicals prove that "when talking about chemicals, most people are not referring to what scientists mean by the same word. The word 'chemicals' is used in everyday language as a shorthand to refer to harmful or potentially dangerous substances. Changing the way people use the word is arguably almost impossible. We should acknowledge that these two different meanings exist, and not worry that people are "getting it wrong". Explaining that 'everything is made of chemicals' will not necessarily change people's views; in fact, the majority of people already know this, and people can hold both meanings of the word as true at the same time.

4. CONCLUSIONS

From the results of the study described in the previous paragraphs different conclusions of large-scale effort can be drawn. The young population represented in this study, mainly composed of Italian people under 30 years

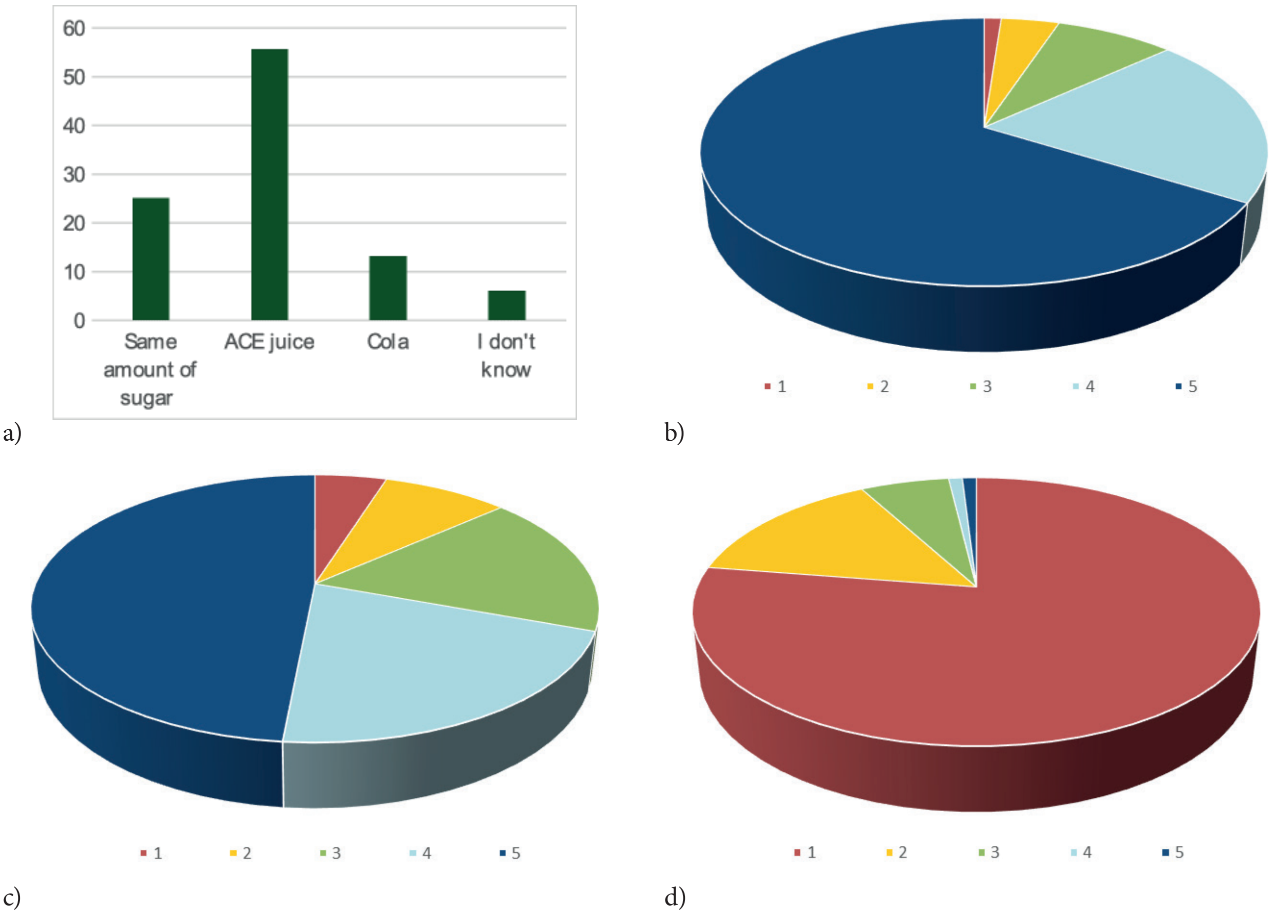

Figure 11. (a) Distribution of answer, expressed as percentage values, related to the correct calculation of the amount of sugar in the two cans. The correct answer is 'b'. The others are wrong. (b) Distribution of answer, expressed as percentage values, concerning the statement: 'Everything is made of chemicals.' People could select between 1 (strongly disagree) and 5 (strongly agree). (c) Distribution of answer, expressed as percentage values, to the statement: 'Everything, including water and oxygen, can be toxic at a certain dose'. People could select between 1 (strongly disagree) and 5 (strongly agree). (d) Distribution of answer, expressed as percentage values, to the statement: 'All chemicals are man-made'. People could select between 1 (strongly disagree) and 5 (strongly agree).

old with a 67% of female, is not representative of the Italian average population, but it offers a good image of the young Italian generations with medium-high education and so it can also be representative of the state of the Italian educational system.

Although there is a part of the population that feels neutral towards chemistry, the majority have a positive approach towards it, in contrast with a condition of neutrality reported in the UK by the RSC's study.[22] It shows that people with a higher level of education are more passionate about theoretical subjects such as chemistry and that education is the key to winning out over the misconceptions and preconceptions linked with the image of chemistry. A large chunk of the public recognizes the importance of chemistry in daily life, and it judges chemicals in a fair manner, contrary to what was expected due to the frequent misuses of the word "chemicals" in the media. Again, this finding shows that a better-educated public understands the value of science – in this case chemistry – and that it is more prone both to recognize that the benefits of chemistry outweigh any harmful effects and to think critically and rationally about chemistry and its potential, rather than letting the media and other sources influence their opinion about it. Since the majority of people registered an interest in the applications of chemistry that can have a positive impact for mankind's problems, such as those related to the environment, technology, energy supply and medical/pharmaceutical advancements, science educators and popularisers should give more relevance to these subjects when engaging with their public because people feel more passionate about things when they can understand a practical use for them.

The results emerging from this study show an evident lack of confidence in talking about chemistry-related topics (48%), comparable with the UK study (58% for women and 45% for men).[22] This feeling of inferiority can justify the observed lack of emotional engagement, that may also be due both to a lack of exposure to the broad range of possibilities of applied chemistry or to inadequate education. Indeed, a large proportion of the public has issues of some kind when approaching the study of chemistry.

In the public unconscious, the idea of chemistry is primarily linked with memories of school days. Similarly to the British study[22] and to the study of perception of chemistry done through the analysis of tweets,[9] the words most frequently associated with chemistry are: 'molecules', 'laboratory', 'matter', 'elements', 'periodic table', 'atoms', 'reactions' and 'teachers'. Thus, teachers play an important role in shaping a young mind's ability to learn, and the fact that a minor but significant proportion of the public considers the teachers they had to be insufficiently prepared negatively affects the awareness and the interest of their students in the field. Though important, this is not the only cause of a tepid relationship with chemistry – a combination of different contributing factors affects the learning process: from inadequate mathematical skills and problems with abstract concepts to a lack of interest and motivation for the subject, inadequate emphasis on day-to-day life applications of chemistry and the fact that a large majority of the public have never seen a chemical-related factory in real life.

The results from the questions investigating the general public's knowledge of chemistry reveal a few gaps in their cultural formation. Although a large majority of the population (58%) had chosen a secondary educational path in which most of the teaching hours were dedicated to Mathematics and Sciences in general, a lot of the sample failed to provide correct answers to very elementary chemistry questions, such as the identification of a chemical reaction, the differentiation of substances from mixtures and the definition of a scientific theory. This trend did not recur for every topic presented: for example, a good understanding of the relation between the symbolic level of chemistry and the representation of the microscopic level was evident. Overall, the patchy competence shown by the participants when asked to provide answers to simple chemical questions bolsters the premise for the lack of confidence already reported and confirms the public's self-perception of being poorly armed with chemical knowledge. Since a not inconsiderable minority of the public reported problems with the subject caused by a lack of mathematical skills, this finding suggests that certain chemistry topics should be taught only after certain specific goals are achieved in the other complementary scientific subjects, such as mathematics and physics, from which chemistry is ultimately derived.

Since most of the people who took part in this study was still in the educational and professional training system, the picture here represented can give an accurate portrayal of the current situation of the Italian school system and the quality of the education offered to its students, and considering that the population of this study achieved a level of education which is higher than the national average, the results relating to the knowledge of the subject are discouraging, indicating that the quality of teaching needs to be improved and that even the section of the population that has proceeded further in their studies fail to achieve an adequate level of knowledge of chemistry.

Conflicts of Interest: The authors declare no conflict of interest.

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APPENDIX A

Questions of the survey (Note that the original questions were in Italian)

1) How old are you?
☐ <18 years old
☐ 18-24 years old
☐ 25-30 years old
☐ 30-40 years old
☐ >40 years old

2) What is the highest level of education you have completed?
☐ Secondary school
☐ Undergraduate degree
☐ Postgraduate degree
☐ PhD
☐ Other

3) Which type of educational path did you take at secondary level?
☐ Scientific lyceum
☐ Classical lyceum
☐ Linguistic lyceum
☐ Artistic/musical lyceum
☐ Sociopsychological/educational lyceum
☐ Technical institute (economic)
☐ Technical institute (technical/scientific)
☐ Vocational institute (hospitality)
☐ Vocational institute (production and construction)
☐ Other

4) What did you study at university?
☐ I didn't go to university
☐ Engineering
☐ Architecture
☐ Medicine
☐ Veterinary science
☐ Paramedical professions (dietician, nurse, obstetrician, physiotherapist etc.)
☐ Law, Social sciences, Economics
☐ Humanities (Literature, Foreign Languages, History, Philosophy, Communication, Education, Music etc.)
☐ Mathematics
☐ Physics
☐ Natural sciences (including Biology, Biotechnology, Geology etc.)
☐ Pharmacology
☐ Chemistry/Industrial Chemistry
☐ Other

5) What is your current occupational status?
☐ Student
☐ Working
☐ Unemployed
☐ Other

6) What is your gender?
☐ Male
☐ Female
☐ Other

7) What do you mentally associate with chemistry? (minimum 100 characters)
This is a very open question and the reply is purely subjective. Brainstorming is encouraged.
(Open question)

8) How do you feel about chemistry?
☐ Neutral
☐ Enthusiastic
☐ Happy
☐ Confused
☐ Bored
☐ Sad
☐ Angry
☐ Shocked
☐ Other

9) How important is chemistry in daily life?
1. Unnecessary
2.
3.
4.
5. Necessary

10) How would you describe your relationship with the study of chemistry?
1. Awful
2.
3.
4.
5. Very good

11) What kinds of problems have you encountered when studying chemistry?
☐ Problems with abstract concepts
☐ Chemistry is inherently difficult
☐ Lack of incentive and motivation
☐ Inadequate textbooks and course materials
☐ Poor mathematical skills
☐ Not enough study and practice
☐ Poor study skills

☐ Not enough emphasis on the day-to-day life applications of chemistry
☐ None
☐ Other

12) How important has the role of the teacher been in learning and studying chemistry?
1. Unimportant
2.
3.
4.
5. Very important

13) How well-prepared were your chemistry teachers?
1. Very poorly
2.
3.
4.
5. Very well

14) In your opinion, what are the negative aspects of Italian schools? And what would you do to improve them?
(*Optional open question*)

15) "I feel confident enough to talk about chemistry." To what extent do you agree with this statement?
1. Strongly disagree
2.
3.
4.
5. Totally agree

16) Where do you encounter topics connected with chemistry?
☐ TV programmes (eg documentaries)
☐ TV series
☐ Blogs
☐ Facebook, Twitter and other social networks
☐ Youtube
☐ Advertisements
☐ Newspapers
☐ News programmes
☐ Conferences
☐ Books
☐ Conversations with other people
☐ Scientific journals
☐ I don't encounter them
☐ Other

17) Which application of chemistry would you be interested in studying further?
☐ Theoretical chemistry
☐ Industrial chemistry (e.g. development of new, environmentally-friendly technology and processes)
☐ Chemistry of art (e.g. conservation and restoration of artworks)
☐ Medical chemistry (e.g. development of new drugs)
☐ Technological chemistry (e.g. development of biodegradable polymers)
☐ Environmental chemistry (e.g. energy solutions, water purification etc.)
☐ Food chemistry (e.g. development of agricultural technology to increase production, molecular cuisine)
☐ None
☐ Other

18) What could be done to improve the image of chemistry?
☐ Increase the number of teaching hours for chemistry
☐ Devote more lesson time to everyday applications of chemistry
☐ More effort on the part of scientists to expose the masses to chemistry
☐ Clearer explanations from scientists in the discussion of chemistry
☐ I'm not interested in improving the image of chemistry
☐ I don't know
☐ Other

19) Have you ever visited a chemical-related factory?
☐ I have never visited one
☐ Paper
☐ Glass
☐ Colourants and paints
☐ Fertilisers
☐ Inorganic compounds
☐ Petrol and fuel
☐ Soaps, detergents and cosmetics
☐ Plastic and synthetic fibres
☐ Pharmaceutical products
☐ Explosives
☐ Other

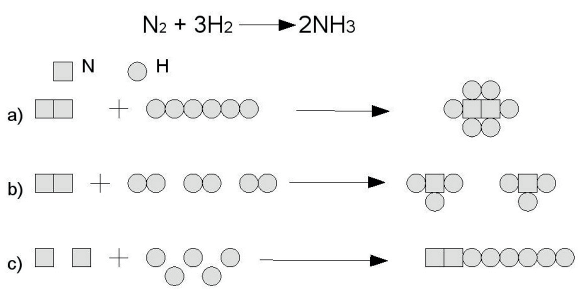
20) Do you have any comments to add about the image of chemistry?
(*Optional open question*)

21) How would you rate your knowledge of chemistry?
1. Completely inadequate
2.
3.
4.
5. Very good

22) In scientific terms, what is a theory? Explain in your own words – you need not give a formal or overly elaborate definition.
(Open question)

23) Which of the following are chemical reactions? You can give more than one reply.
☐ Solution of sugar in water
☐ Evaporation of water
☐ Dilution of fruit juice concentrate
☐ Rusting of an iron nail in air
☐ Browning of the cut surface of a slice of fruit
☐ Combustion of sugar in the presence of oxygen

24) The equation for the reaction which produces ammonia is written at the top, and the images below show a few possible molecular representations of the reaction…



… which of these is correct?
a)
b)
c)
None of these

25) Which of these are substances and not mixtures of substances?
☐ Milk
☐ Iron
☐ Tap water
☐ Steel
☐ Sand
☐ Table salt
☐ Oxygen

26) A 330ml can of Coca-Cola contains 36.3g of sugar whilst an ACE juice contains 12.1g of sugar per 100ml. In the same quantity, which of the two drinks contains more sugar?
☐ Cola
☐ ACE juice
☐ Same amount of sugar
☐ I don't know

27) "Everything is made of chemicals"
Do you agree with this statement?
1. Strongly disagree
2.
3.
4.
5. Totally agree

28) "Everything, including water and oxygen, can be toxic at a certain dose."
Do you agree with this statement?
1. Strongly disagree
2.
3.
4.
5. Totally agree

29) "All chemicals are man-made."
Do you agree with this statement?
1. Strongly disagree
2.
3.
4.
5. Totally agree

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Feature Articles

Preliminary Investigation of Microplastics in Roadside Soils of Port Harcourt and Elele in Rivers State, Nigeria

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Abstract. This study evaluated the occurrence of microplastics in roadside soils in Port Harcourt and Elele, Rivers State, Nigeria. Topsoil samples were collected from three major road networks in Rivers State (Port Harcourt city internal roads, Port Harcourt to Elele Road, and Elele to Owerri road). Microplastics were extracted from the samples using density separation and quantified via microscopy. Microplastic abundances in the samples ranged from 3 particles/50 gram - 20 particles/50 gram. The highest number of microplastic particles were found on roads with the highest traffic density. Secondary microplastics were most abundant in the samples as fragments constituted 69% of the total plastics and made up 67%, 73% and 70% of Port Harcourt internal roads, Port Harcourt to Elele road and Elele to Owerri road, respectively. This study presents baseline data on microplastics in roadside soils in an urban Nigerian city and highlights the contribution of road traffic and vehicles to both terrestrial and aquatic microplastics as well as the need for routine monitoring in order to mitigate plastic pollution.

Keywords: Plastic Pollution, Road traffic density, Terrestrial microplastics, Microplastic fragments; Urban runoff

INTRODUCTION

Plastic use in Nigeria has grown over the years to become an essential part of everyday life due to its favourable properties such as affordability, durability and wide application in various sectors such as health, food and beverage packaging, textile and agriculture.[1-3] Annual plastic use in Nigeria has grown from 1 million in 2015 to 1.5 million tons in 2020.[4] Furthermore, more than 5 million sachet water packages are disposed of per day in Nigeria without any plan for recycling or proper management. Increasing plastic use has led to increased plastic disposal, and due to poor waste management system and recycling infrastructure in Nigeria, plastic wastes accumulate, pollute the environment and inevitably end up in the marine and freshwater ecosystems.[5-7] Plastic waste management has remained one of Nigeria's greatest environmental challenges.[8] Recently, the Lagos state government banned the use of single-use plastics (SUPs) in the state because they block the stormwater channels, causing flooding in the country's commercial and most populous state.[9] Plastics, when littered in the environment fragment into microplastics because of diverse environmental and biological factors.

Microplastics are plastic particles that are less than 5 mm in any one dimension. They are either primary microplastics when they are intentionally produced to be 5 mm, or secondary microplastics when they break out from larger plastic materials in diverse shapes such as fragments, fibers, and films.[10] Microplastics are persistent in the environment and can be transported from one ecosystem to another causing harm to biodiversity when ingested by organisms or via entanglement. Toxic plastic constituents may also leach from microplastics, contaminating the environment. In some cases, microplastics transport pollutants from highly polluted area to less polluted or pristine environment.[11-13] One of the major sources of pollutants to the aquatic ecosystems is road soils and dusts. Transportation of legacy pollutants such as polychlorinated biphenyls, petroleum hydrocarbons and heavy metals from road soils to aquatic ecosystems have been reported in literature.[14-17] Also, microplastics have been reported to be transported from roadside soils and dusts into aquatic ecosystems.[18-20] Furthermore, vehicle parts and tires are significant sources of microplastics due to wear and tear as well as friction between tires and road surfaces leading to release of tire particles on the road.[21] Thus, roadside soils may be huge reservoir of microplastics. As emerging pollutants, adverse effects of microplastics on biodiversity include reduced fertility, oxidative stress, poor feeding and growth, change in soil properties and reduced crop yield.[22-26]

Currently, there is no data on plastic pollution in road soils in Nigeria except for Okigwe road in Imo state.[27] Effects such as microplastics contamination of garri (cassava flakes) spread on roadside for drying have also been reported by Enyoh *et al*.[28] Therefore, this study aimed to evaluate the occurrence of microplastics in roadside soils in Port Harcourt and Elele in Rivers State, Nigeria. The result of this study is expected to provide baseline data on microplastic pollution of roadside soil.

MATERIALS AND METHODS

Study Area

Rivers state is located in the Niger Delta region of southern Nigeria (Figure 1). It is a commercial and industrialised state considered to be the commercial centre of the Nigerian crude oil industry. The roads usually witness high traffic density in major urban areas and city outskirts especially the roads leading to other state capitals like the Port Harcourt-Elele-Owerri road which was the centre of this study.

Figure 1. Map of Nigeria showing Rivers State (in gray)

Sample Collection

Topsoil samples (0-5 cm depth) were collected from roadside soils besides (≈ 2m) high traffic and low traffic density roads in Port Harcourt and outskirts (Elele-Owerri road) in Rivers State with metallic spoon, transferred into aluminium foils and taken to the laboratory for further analysis. Samples were collected at multiple points at each sampling location and later mixed in the laboratory to make a composite sample. Sampling locations and geographical coordinates are presented in Table 1.

Table 1. Sampling locations and geographical coordinates

Sampling location	Latitude	Longitude
Benjack Junction	4.8352 °N	7.0143 °E
Tontex Garden Centre	4.8352 °N	7.0233 °E
Madonna University Gate	5.9314 °N	6.8376 °E
Rivers Joy, Rumudumaya	4.9040 °N	7.0003 °E
Madonna University Church Gate	5.1344 °N	6.8270 °E
Port Harcourt Airport Road	5.0157 °N	6.9541 °E
Salvation Ministry Igwuruta	4.9421 °N	7.0117 °E
The Promise, Elele	5.0083 °N	6.9114 °E
Market Junction	5.1029 °N	6.8121 °E
St. Aquinas Secondary School, Elele	49936 °N	6.9142 °E
Elekahia Housing Estate	4.8134 °N	7.0237 °E
HCUE Restaurant	4.7844 °N	7.0384 °E
Rumumasi Market	4.8331 °N	7.0292 °E
Asaga Junction	5.1018 °N	6.8190 °E
Greater Evangelism Headquarter	4.9293 °N	6.9971 °E
Betylino Int'd Limited	5.1138 °N	6.8243 °E
SPDC Pipeline	4.8944 °N	7.0055 °E
TNC Hotel	4.8934 °N	7.0072 °E
Rumuheinwo Housing Estate	4.8934 °N	7.0024 °E
Regeneration School	4.8939 °N	7.0065 °E

Density Separation and Microplastic Quantification

Saturated solution of sodium chloride (300 g/L) was added to 50 g of soil samples in a volumetric flask. Samples were stirred for ten minutes and kept for 24 hours to settle while covered with aluminium foil.[29] The mixture was decanted through a vacuum separation system. The residue on the filter paper was dried in an oven (40 °C), stored in glass petri dishes, and used for microplastic quantification. The filter paper was viewed under Olympus Compound Light Microscope (x40) and microplastic in soil samples (50 g) were identified, counted, shapes recorded, and their photographs taken.

Quality Control

Only glass wares were used for this study to avoid contamination from plastic products. Double distilled water used for the study were also pre-filtered to avoid contamination. Samples were covered with aluminium foils when not in use and all processes were done in fume cupboard to prevent air-borne contamination. Blank samples were also analysed to ensure removal of any contamination during the sample preparation and analysis.

RESULTS AND DISCUSSION

Microplastic Abundance

The number of microplastics in the roadside soils ranged from 3 to 20 particles/50g. The highest concentration of microplastics was found in Benjack roadside soils (20 particles/ 50g) while the least concentration of microplastics was found in Rumuomasi roadside soils. Benjack junction is a major road intersection that services one of the major commercial areas in Port Harcourt with occasional stops due to traffic controls and a high traffic burden. This may be the reason for the high microplastic concentration in the roadside soils from the road. Microplastics were present in all samples except the soil samples from around TNC Hotel (Figure 2). Microplastics abundances were highest in Port Harcourt roads (69 particles) and Port Harcourt-Elele Road (69 particles) followed by Elele-Owerri road (37 particles). Soils from roadsides with high traffic density constitute 69% of all microplastics found in the study while soils from low traffic density roads made up 31% (Figure 3). This confirms that vehicles/vehicular traffic contributes microplastics to roadside soils as also seen in Ben-

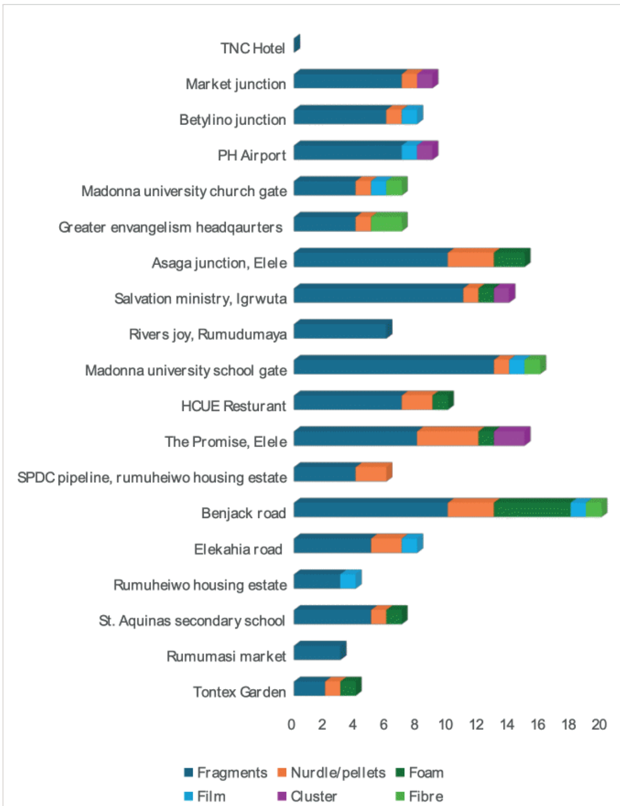

Figure 2. Microplastic abundance in Rivers State roadside soils (particles/50g)

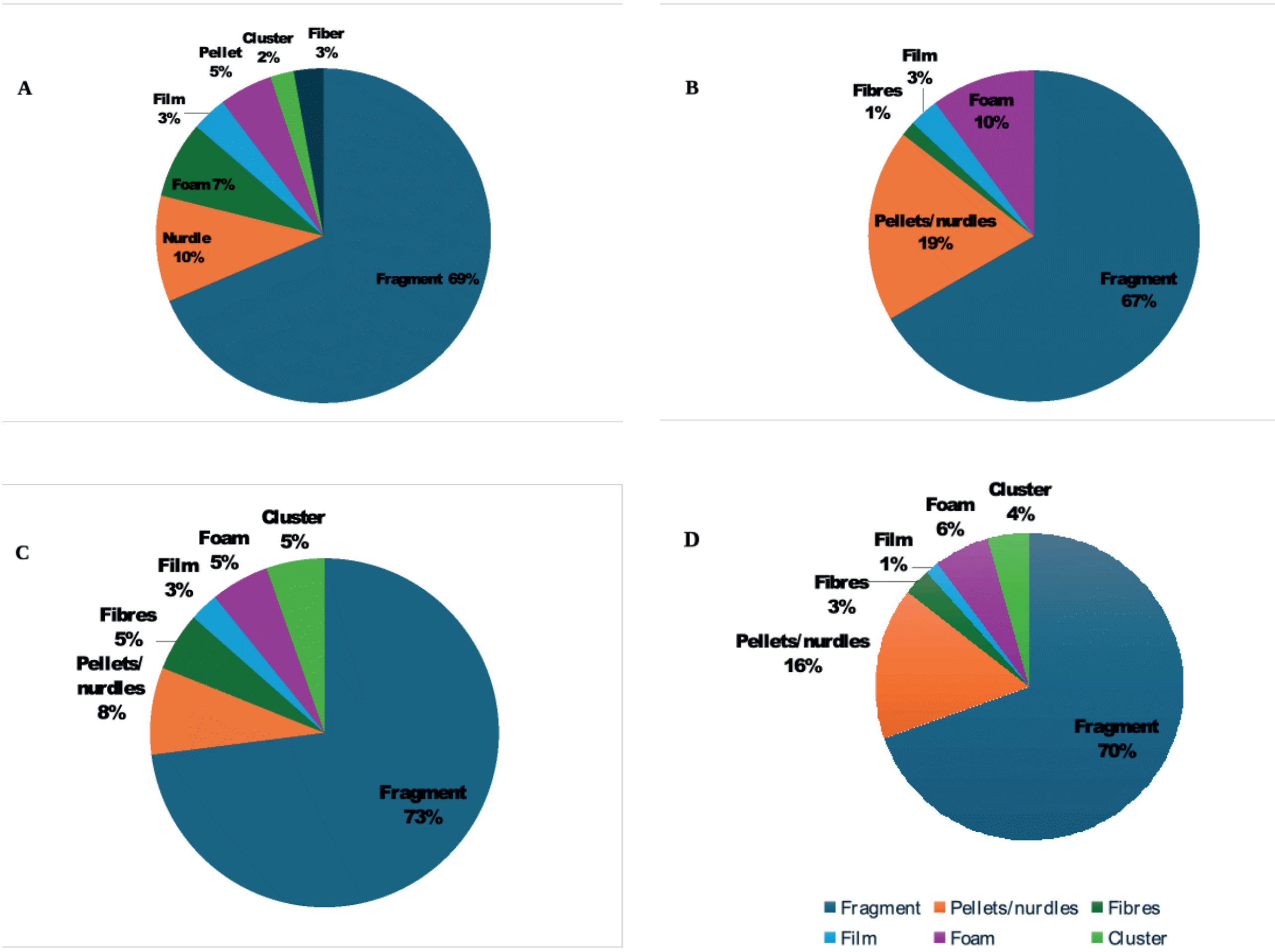

Figure 3. Percentage composition of microplastic shapes in A): total road soils B): Port Harcourt internal roads C): Port Harcourt to Elele Road D): Elele to Owerri road

jack roadside soils.[30, 31] There are a few studies on microplastics in roadside soils to compare to the result of this study. However, the microplastics in roadside soils from Port Harcourt roads were higher than the microplastics in roadside soils and dusts in rural and urban roads in Victoria, Australia and in soils on roadside soils of Qinghai, Tibet Plateau. [32, 33] Pellet was the highest occurring microplastics in Qinghai roads while fibers occurred most frequently in the Victoria study in Australia. This is in contrast with the Port Harcourt roads which were dominated by fragments.

The correlation between traffic density and the microplastic concentration in the studied roadside soils shows a weak positive correlation with a correlation coefficient of 0.27 (Figure 3 and Table 2). This shows that there may be other factors contributing to microplastic abundance in roadside soils besides vehicles. These other sources may include atmospheric deposition, rainfall, storm water flow and improper waste disposal.[34] Microplastic particles deposited on roadside soils may also be transported farther away from the roads by storm water from precipitations.

Microplastic Shapes

The percentage of the constituent shapes of the microplastics in each sampling location is described in Figure 3. Fragments were the most frequently occurring microplastics in all samples followed by pellets (Figure 5). Soil microplastic studies usually report fragments and pellets as the most abundant microplastic shapes.[30, 35, 36] These fragments may have been from vehicular parts or transported by rainwater runoff.[37] The fragments also show the microplastics are secondary microplastics from larger plastic materials unlike pellets/nurdles which are

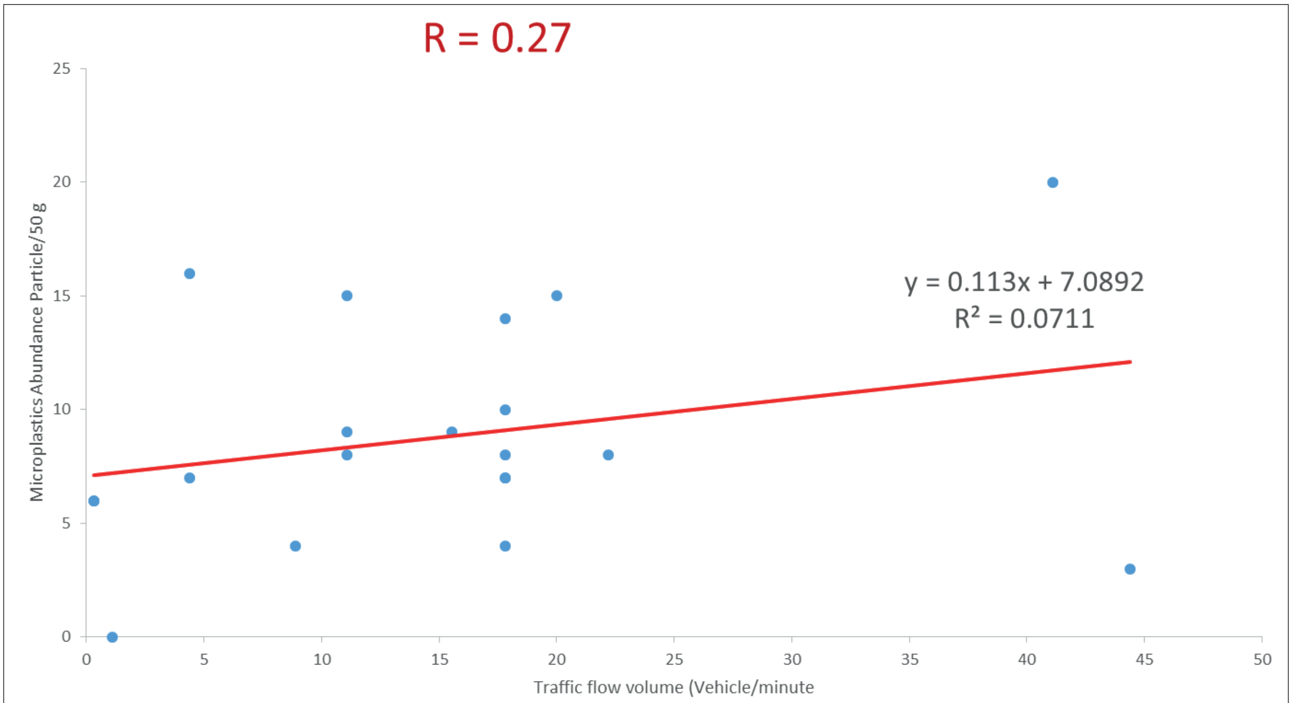

Figure 4. Correlation between traffic density and microplastic abundance

primary microplastics. The presence of fibers indicate secondary microplastic sources from vehicular tire wear, road markings, clothing and ropes during runoff.[18, 38-40] Other microplastic shapes identified in the samples are also secondary microplastics. Individually, fragments made up 67% of microplastics in Port Harcourt roads and 73% of microplastics in Port Harcourt-Elele Road and 70% in Elele-Owerri roads (Figure 4).

CONCLUSIONS

This preliminary study intends to draw attention to the occurrence of microplastics on roadside soils, particularly in African roads which are currently understudied. It shows that microplastics in Port Harcourt internal roads, Port Harcourt to Owerri road and Port Harcourt to Elele road soils were chiefly fragments, indicating the dominance of microplastics. The microplastic abundance correlated weakly with the traffic density, an indication that vehicle traffic may not be the only source of microplastics on roadside soils. Other microplastic shapes found in the road soil samples were film, foam, fibre and pellets. There is need for more monitoring studies on Nigerian roads to evaluate the contribution of road traffic density to microplastic pollution and how road runoffs and tire particle toxicity affect the freshwater ecosystem.

Table 2: Traffic density of sampling locations (vehicle/minute)

Sampling location	Traffic Density (Vehicle/min)	Microplastic Abundance (Particles/50g)
Benjack Junction	41.10	20.00
Tontex Garden Centre	17.80	4.00
Madonna University Gate	4.40	16.00
Rivers Joy, Rumudumaya	22.20	8.00
Madonna University Church Gate	4.40	7.00
Port Harcourt Airport Road	15.56	9.00
Salvation Ministry Igwuruta	17.80	14.00
The Promise, Elele	20.00	15.00
Market Junction	11.10	9.00
St. Aquinas Secondary School, Elele	17.80	7.00
Elekahia Housing Estate	17.80	8.00
HCUE Restaurant	17.80	10.00
Rumumasi Market	44.40	3.00
Asaga Junction	11.10	15.00
Greater Evangelism Headquarter	17.80	7.00
Betylino Int'd Limited	11.10	8.00
SPDC Pipeline	0.30	6.00
TNC Hotel	1.11	0.00
Rumuheinwo Housing Estate	8.90	4.00
Regeneration School	0.30	6.00

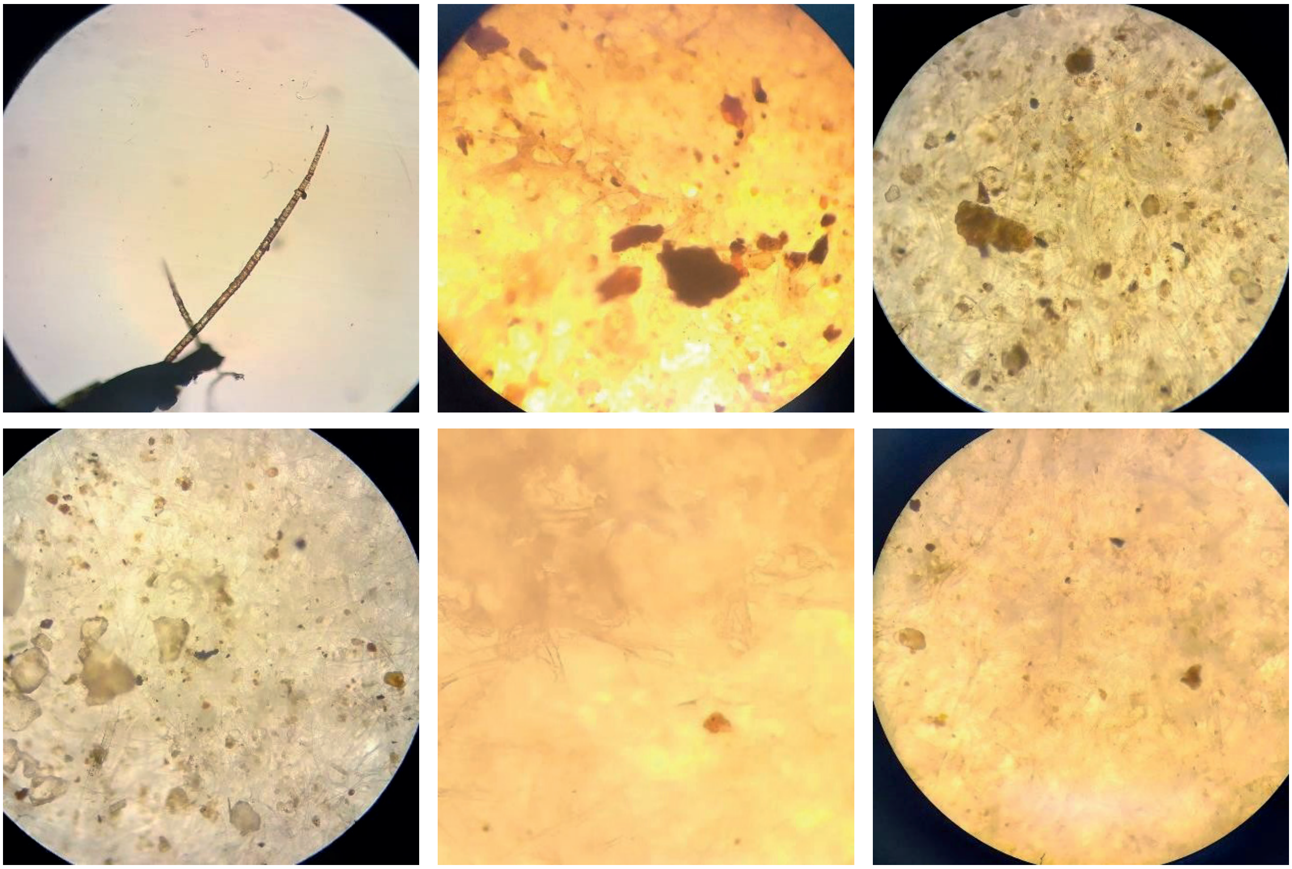

Figure 5. Microscopic fibers and fragments from roadside soils in Port Harcourt

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Feature Articles

The History of the European Colloid and Interface Society

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Abstract. The European Colloid and Interface Society (ECIS) was founded in 1986 to provide a European meeting place for scientists interested in colloids and surfaces, including both chemists, physicists, biologists, and colleagues interested in applications. The annual September conferences have from the start attracted strong interest and in recent years 500-1000 scientists from most European countries have attended in addition to several colleagues from Japan, China, USA, Brazil and Australia. ECIS also arranges bi-annual student conferences and deliver awards to senior and younger scientists.

Keywords: Colloid, Interface, Society, European, History, ECIS

INTRODUCTION

The 37th conference of the European Colloid and Interface Society (ECIS) was held in September 2023 in Naples, Italy. On turning back to Italy, where ECIS was founded in 1986, it seems natural to reflect on the background and start of the society. The number of participants in Naples was 570 demonstrating that ECIS is a very vital organization. Actually, the number of participants was not much less than the record number (808 in Rome 2016). Here we analyze the reasons behind the success of ECIS in relation to the motivations behind its creation.

The story of the founding of ECIS has been well described by Mario Corti on the ECIS home page as follows:

"The great success of the Varenna Summer School on the "*Physics of amphiphiles: micelles, vesicles and microemulsions*" in 1983 organised by Vittorio Degiorgio and myself, along with the editing work of its 750 pages proceedings, convinced us that Colloid Science was an interesting field of research with new opportunities for people in physics, chemistry, biology and technology.

The idea that Colloid and Interface Science could deserve an autonomous organisation on a European basis, with the aim to promote and stimulate the exchange of information among scientist of all European countries, was formulated by Vittorio Degiorgio (Pavia, Italy), Heinz Hoffmann (Bayreuth, Germany) and Bjorn Lindman (Lund, Sweden) during their return trip from the IUPAC conference held in Manchester on September 1985. This idea found the enthusiastic support of many colleagues, including myself and Pierre Bothorel (Bordeaux, France).

Altogether we decided that it was good to organise a Workshop with the aim to test the feelings of the people active in the field. The first suggestion was to organise it in Varenna on Lake Como, just to take advantage of the fame of the successful School. Eventually, we preferred to locate it in Como, town easy to reach by train from central Europe. Vittorio Degiorgio and myself both provided all the organising work and obtained some local financial support, so that we could have the European Workshop "New Trends in Colloid Science" (Villa Olmo, Como, Italy 1–3 October 1986) free of subscription fees, with free lunches and free conference dinner. "Discussion about the Foundation of a European Colloid Society" ECOS (see picture) was part of the program.

A steering committee, formed by Vittorio Degiorgio, Heinz Hoffmann and Bjorn Lindman, prepared a draft of the statutes and by-laws of ECOS. More than one hundred people attended the Workshop. In the afternoon of October 3, 1986, the Society was founded. That day, the initial name of ECOS was changed into ECIS (European Colloid and Interface Society) and the first general assembly of ECIS was held. The steering committee ceased to operate and the first Council of ECIS was elected: Heinz Hoffmann, Pierre Bothorel and myself. The ECIS Secretariat was initially established in Lund at Bjorn Lindman Institute and successively in Bayreuth at Heinz Hoffmann Institute.

The first Conference of ECIS was scheduled for the following year again in Como (September 2-4, 1987), organised by Vittorio Degiorgio and myself. Again no subscription fees were asked."

Around 1980 there was a strongly increased activity in Europe on various research topics within the field of colloids, notably surfactant self-assembly into micelles, microemulsions, surfactant adsorption and biological membranes; there was also an introduction of new experimental techniques like various NMR and scattering approaches and cryo-electron microscopy. Some countries had important national meetings like Germany and the UK and there was also a series of Scandinavian meetings started by the leading scientist Per Ekwall (professor of Åbo Akademi in Finland and on his retirement creating the Institute of Surface Chemistry in Stockholm). There were several meetings that brought scientists together over the national borders like the Kolloidtagung in Bayreuth in 1983 and the Surfactants in Solution conference in Lund in 1982 and other meetings in Lund in 1984. Around that time contacts were also established with our French colleagues, in particular with Pierre Bothorel at CRPP in Bordeaux. He and his coworkers came to the Scandinavian meeting in Copenhagen in 1982 and he organized the Surfactants in Solution conference in Bordeaux in 1984.

However, the meetings hosted by our Italian colleagues were particularly important and everyone who attended the Varenna meeting in 1983 will remember the nice atmosphere and the fruitful discussions. Fortunately, Mario Corti and Vittorio Degiorgio documented this in a book still worth studying. As can be learnt from Ref. 1 many leading scientists contributed like Jacob Israelachvili, John Hayter, Peter Pusey, Dominique Langevin, Heinz Hoffmann, Björn Lindman, Manfred Kahlweit, George Benedek, S. H. Chen, Ken Dill, Bill Gelbart, Arieh Ben-Shaul, Charles Tanford, J. A. Reynolds, Pierre Bothorel, Christiane Taupin, and Francoise Candau.

The ground was therefore more or less made when, as Mario describes, Vittorio, Heinz and the author met in Manchester in 1985. However, the significant step was of course that Vittorio and Mario took the work and efforts to invite to the foundation meeting at Lake Como in 1986. There the statutes and plans for coming meetings were made.

It is interesting to note that neither of us (Heinz, Vittorio, Mario and the author) had any established position in the field of colloids at the time. Rather our competence and focus layed on experimental techniques, for Heinz on fast kinetics, for Vittorio and Mario on scattering techniques whereas we in Lund were focusing on novel NMR techniques, like ion NMR and self-diffusion. However, we were brought together by focusing our research on the same systems, namely surfactant self-assemblies, a controversial and emerging field at the time. Surfactant systems were a large part of the presentations at early ECIS conferences but now there is a much larger breadth of topics. Thus, looking in the programs of the first ECIS meetings it can be inferred that the scopes were somewhat limited and reflected to a considerable extent the interests of the founders. Important topics in the field of surfactants studied at the time included theory of self-assembly, molecular interactions involved, dynamics and kinetics of aggregates, aggregate shape and size, rheological properties and relevance for biological systems. Leading scientists in addition to those involved in ECIS include Jacob Israelachvili, Gordon Tiddy, Barry Ninham, Charles Tanford, Håkan Wennerström, Manfred Kahlweit, Kozo Shinoda, Per Ekwall, Krister Fontell, Stig Friberg, Raoul Zana, George Benedek, Francoise Candau, Egon Matijevic, Theo Overbeek, Hans Lyklema, Henk Lekkerkerker, and Dominique Langevin.

ECIS INITIATORS

Several colleagues contributed to the early development of ECIS thus laying the ground for the later success of the organization. The basis lies in their research interests and excellence here described in a few words.

Heinz Hoffmann started his research career in electrochemistry at the TH Karlsruhe and during a postdoc stay he became interested in the field of fast reaction kinetics. He entered the field of colloids by groundbreaking observations on micellar kinetics. Shortly later, in 1975, he became appointed as a full professor to the University of Bayreuth, at that time a newly founded university, where he started the field of physical chemistry and stayed ever after, by now being a professor emeritus there since 2003. Heinz Hoffmann contributed largely to many different fields of colloid science, including micellar growth, phase diagrams, microemulsions and block copolymers during his long scientific career. (See further Ref. 2.) Heinz Hoffmann was always in his career very interested in bridging the gap between fundamental science and its applications, which resulted naturally in many industry collaborations. An openness to the broad scientific community was certainly one of the driving forces why he became one of the founding fathers of ECIS.

Figure 1. Heinz Hoffmann. Courtesy of ECIS.

Vittorio Degiorgio was a physicist by training and made ground-breaking contributions on laser physics and nonlinear optics. He was during a long time professor of physics at the University of Pavia, Italy. His early career took place in Milan at the Polytechnic University but included also a very successful postdoctoral stay at MIT. Vittorio's first important contributions in the field of colloid science came in the end of the 1970's and the early 1980's with studies of surfactant micelles by laser light scattering. During decades he was a leader in colloid science with his scattering studies of different surfactant self-assemblies, in particular micelles and liquid crystals. Besides his scientific contributions he played a very important role in our scientific community by organizing and hosting conferences and summer schools, like the one in Varenna in 1983 on Physics of Amphiphiles. Vittorio Degiorgio passed away in 2021 after suffering from cancer for several years (Ref. 3).

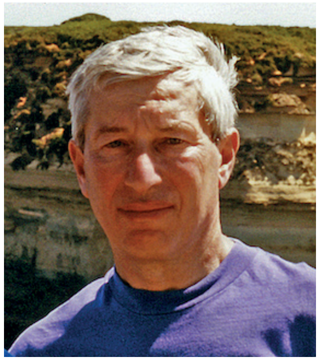

Figure 2. Vittorio Degiorgio. Courtesy of ECIS.

Björn Lindman started his Ph D work at the Royal Institute of Technology in Stockholm working on new NMR techniques to study electrolyte solutions. His studies included ion NMR and self-diffusion on simple solutions but in particular proteins and amphiphiles. During the 1970s he held a position as a researcher in Biochemical Molecular Spectroscopy at the Swedish Science Research Council and in 1978 he became full professor in physical chemistry at Lund University. The NMR techniques he had learnt proved particularly useful for surfactant systems and at the end of the 1970s and the beginning of the 1980s he focused his research on micelles and microemulsions (Ref. 4). He shared for a long period his time between Lund and Coimbra University, Portugal. After his retirement from these universities, he held positions at MidSweden University and Nanyang Technological University, Singapore. He is now emeritus professor in Lund and Coimbra.

Figure 3. Björn Lindman. Courtesy of ECIS.

Whereas the idea of ECIS initially came up in a meeting between Heinz Hoffmann, Vittorio Degiorgio and Björn Lindman, two other colleagues played a critical role in the foundation of the society, Mario Corti as organizer of key meetings in Italy, including the meeting in Como for the foundation of ECIS, and Pierre Bothorel as leader and representative of a strong French community of colloids and surfaces; Pierre was involved in the direction of ECIS from the start and also organized the second ECIS conference.

Mario Corti graduated in Physics at the University of Milan, starting his scientific career in the field of low energy nuclear physics, working experimentally at the Van de Graaf accelerator. There he got acquainted with fast electronics and to radiation detection techniques. With the advent of lasers, he shifted to Quantum Electronics. He developed fast correlation techniques to measure properties of optical fields and in 1974 he published the paper describing the first fast real-time digital correlator, ensuring high-performance static, dynamic, polarized and depolarized light scattering experiments. The first applications were on pure fluids and binary mixtures but soon he turned to colloid suspensions, including non-ionic micelles. Mario also pioneered the field of ionic micellar solutions, concerning both the determination of their shape and size near the critical micelle concentration and their role as interesting systems to model interactions in colloidal solutions. Later on, he turned to biologically relevant amphiphiles, namely glycolipids, entering an interdisciplinary field, nearly unexplored at that time, bridging physics and biochemistry. While working in the CISE Research Centre (1965-1986) he performed teaching activity at the Physics Department of the University of Milan, until 1987 when he was appointed Full Professor of Physics at the Faculty of Engineering of the University of Pavia. From 1995 to 2011 (year of retirement) he was Full Professor of Medical Physics at the Faculty of Medicine at the University of Milan.

Figure 4. Mario Corti. Courtesy of ECIS.

Pierre Bothorel had as a long-term director of Centre de Recherche Paul Pascal a central role in French research in the area. His background was in research by advanced optical techniques on molecular properties, like optical anisotropy. He entered the field of colloid science in studies of conformational states of lipid chains, of phospholipid mono- and bilayers and of biological membranes, while in the early 1980's he made very thorough studies on microemulsions, both on phase behaviour and molecular packing. He was strongly involved in creating scientific contacts on the European level and organized in the 1980's two significant scientific meetings.

The start. In 1983, Vittorio Degiorgio and Mario Corti organized the Course of the Varenna International School "Enrico Fermi" entitled "Physics of Amphiphiles: Micelles, Vesicles and Microemulsions". This was a pioneering event in the field now called nanotechnology. Physicists, physical chemists, biochemists and biologists got together for a couple of weeks with a synergic approach. The Proceedings of the School, edited by V. Degiorgio and M. Corti, were largely appreciated by the scientific community. The ideas born in the Varenna School were developed further in the two Como meetings (again organized by V. Degiorgio and M. Corti) bringing to the convincement that it was the right time for the foundation of a European Society in the colloid field. The 1986 Como meeting was then the founding event of the European Colloid and Interface Society (ECIS). Founders were H. Hoffmann (Germany), P. Bothorel (France), B. Lindman (Sweden), V. Degiorgio (Italy) and M. Corti (Italy), who was in charge of organizing the first ECIS meeting, held in Como in 1987. Mario Corti was President of ECIS during 1989.

The development and continuity of ECIS were very dependent on the support and work of a number of leading colleagues in the field including Conxita Solans, Nalle Rosenholm, Otto Glatter, Aris Xenakis, Thomas Zemb, Brian Vincent, Kenneth Dawson and others. By their regular participation in the conferences and acting as presidents and conference organizers they contributed strongly to ECIS.

MANAGEMENT AND ADMINISTRATION

ECIS started very informally with advertisements and invitations through regular mail and personal contacts and much work was carried out by the meeting organizers. At the conferences, in addition to the regular scientific presentations, there was also a general meeting dealing mainly with the location and organization of the meeting of the coming year, a General Assembly. From the beginning a council consisting of three persons was elected to handle the direction of ECIS. Also, a general secretary of ECIS was appointed. The presidents served for one year initially, but this changed later to 2 years. The first council consisted of Heinz Hoffmann (president), Mario Corti and Pierre Bothorel whereas the first general secretary was Gerd Olofsson, Lund.

The following persons have served as presidents of ECIS:

Tommy Nylander (SE) 2024–2025
Epameinondas Leontidis (CY) 2022-2023
Dganit Danino (IL) 2020-2021
Elena Mileva (BG) 2018-2019
Piotr Warszynski (PL) 2016-2017
Debora Berti (IT) 2014-2015
Reinhard Miller (DE) 2012-2013
Andrew Howe (UK) 2010-2011
Maria da Graça Miguel (PT) 2008-2009
Kenneth Dawson (IR) 2006-2007
Martin Cohen Stuart (NL) 2004-2005
Helmut Möhwald (DE) 2003
Otto Glatter (AT) 2002
Thomas Zemb (FR) 2001
Jarl Rosenholm (FI) 2000
Björn Lindman (SE)1998-1999
Conxita Solans (ES) 1997
Henk Lekkerkerker (NL)1996
Peter Schurtenberger (CH) 1995
Per Stenius (FI) 1994
Dominique Langevin (FR) 1993
Peter Laggner (AT) 1992
Mats Almgren (SE) 1991
Ronald H Ottewill (UK) 1990
Mario Corti (IT) 1989
Pierre Bothorel (FR) 1988

The ECIS secretariat was initially located in Lund and afterwards for a long period in Bayreuth. ECIS secretaries have been Gerd Olofsson, SE (1987-1989), Heinz Hoffmann, DE, (1990-2000), Jarl Rosenholm, FI (2000-2002), Peter Schurtenberger, CH (2002-2010), Peter A. Kralchevsky, BG (2010-2021) and Pierandrea Lo Nostro, IT (2021-present).

More recently, with the growth of ECIS and the increase of its economy, a position as treasurer has been created and also one as webmaster. Hans-Jürgen Butt, DE (2010-2016), Andreas Fery, DE (2016-2022) and Matthias Karg, DE (2022-) have served as treasurers and Peter Schurtenberger, CH (1994-2002), Otto Glatter, AT (2002-2010), Pierandrea Lo Nostro, IT (2010-2021) and Dominik Horinek, DE (2021-present) as Webmasters.

Figure 5. Jarl Rosenholm, ECIS secretary, president and conference organizer, and Peter Schurtenberger ECIS secretary, president, honorary member and Overbeek Awardee. Courtesy of ECIS.

Membership fees were initially paid individually by the members a procedure found complicated. Therefore, it was arranged that members attending the ECIS conferences could pay their fees together with the registration fee. When ECIS started, contacts between East and West were still restricted causing problems of conference participation but also in handling membership fees.

OTHER ORGANIZATIONS

As touched upon above there existed long before ECIS strong national organizations in the field in a few countries like Germany (Kolloid-Gesellschaft) and UK (Colloid&Interface Science Group) in particular. The meetings of those attracted a limited number of participants from other countries. In addition, there were a limited number of larger meetings in different countries but without regularity and coordination.

The first major international regular conferences in colloid and interface science started in the 1970s in Budapest and Puerto Rico, USA and these together with a group within the International Union of Pure and Applied Chemistry (IUPAC) and a newsletter due to Hans Lyklema, formed the basis of Geoff Parfitt taking the initiative to form IACIS, the International Association of Colloid and Interface Scientists. The official foundation took place in the conference in Stockholm in 1979. IACIS has grown into a strong global association with tri-annual conferences all over the world (including the US, Australia, Brazil, Japan, China, and several European countries). A photo of the founders of IACIS is given in Figure 6.

When the plans for ECIS came up it was natural that its relation to IACIS was considered. Some leading members of IACIS suggested that ECIS should be a section of IACIS, but the final solution was that the two organizations sent a representative to the council of the other organization. The participation of IACIS and ECIS conferences has from the beginning been strongly overlapping and this concerns also the management. Per Stenius, Reinhard Miller and Björn Lindman have been presidents of both organizations.

One of the founders of IACIS was Hans Lyklema from Wageningen in the Netherlands. He was also in other respects a key figure in creating relations in the international community. Noting the difficulties for scientists from the Eastern European countries in attending conferences outside the Warsaw bloc he started a series of conferences, European Chemistry at Interfaces (ECIC). These conferences alternated between western and eastern Europe and were very successful not only for the creation of contacts and collaboration in Europe but also had very good attendance. After the fall of the Berlin Wall in 1989 the motivation for these separate conferences decreased and a merging with ECIS was natural.

Figure 7. Hans Lyklema. Courtesy of ECIS.

ECIS LOGO

In 2012 it was decided to consider a renewal of the original ECIS logo and at the General Assembly in Malmö new proposals were presented. In a voting including the old logo and 3 new proposals the current logo was elected. The designers of the new ECIS logo are Ana Kroflič and Robert Rep from the Department of Physical Chemistry, University of Ljubljana, Slovenia.

Figure 6. First IACIS Council at the foundation in Stockholm 1979. From left: Alexi Scheludko (Bulgaria), Boris Deryagin (USSR), Hans Lyklema (Netherlands), Tom Healy, Geoff Parfitt, Lisbeth Ter-Minassian-Saraga (France), Erwin Wolfram (Hungary), Per Stenius (Sweden), Armin Weiss (West Germany), Božo Tezak (Croatia, Yugoslavia), Egon Matijevic (USA) and Eiji Suito (Japan). Not shown are Alex Silberberg (Israel) and Gabor Somorjai (USA) as well as the secretary H.O. Becker (Germany).

Figure 8. Previous and current ECIS logos. Courtesy of ECIS

CONFERENCES

The annual ECIS conferences taking place in September have been widely spread over Europe as can be seen from this list:

2024: Copenhagen (DK)
2023: Naples (IT)
2022: Chania (Crete, GR)
2021: Athens (GR)
2020: *Online Event (IL)*
2019: Leuven (BE)
2018: Ljubljana (SLO)
2017: Madrid (ES)
2016: Roma (IT)
2015: Bordeaux (FR)
2014: Limassol (CY)
2013: Sofia (BG)
2012: Malmö-Lund (SE)
2011: Berlin (DE)
2010: Prague (CZ)
2009: Antalya (TR)
2008: Krakow (PL)
2007: Geneva (CH)
2006: Budapest (HU)
2005: Geilo (NO)
2004: Almeria (ES)
2003: Firenze (IT)
2002: Paris (FR)
2001: Coimbra (PT)
2000: Patras (GR)
1999: Dublin (IE)
1998: Dubrovnik (HR)
1997: Lunteren (NL)
1996: Turku (FI)
1995: Barcelona (ES)
1994: Montpellier (FR)
1993: Bristol (UK)
1992: Graz (AT)
1991: Mainz (DE)
1990: Copanello (IT)
1989: Basel (CH)
1988: Arcachon (FR)
1987: Como (IT)

No less than 24 countries have hosted ECIS conferences; the countries particularly active are Italy (the 2023 conference was the 5th), France (3), Greece (3) and Spain (3).

In early ECIS meetings a principle was to avoid parallel oral sessions to stimulate discussions; with the increasing number of participants this principle had soon to be abandoned. Another principle was to promote oral presentations from younger researchers. The increasing number of young scientists motivated the creation of a separate forum for them, the ECIS Student Conferences. These biannual conferences were started by Brian Vincent in 2003 and have been organized in Italy, Bulgaria, UK, Sweden (2), Poland, Hungary, Spain, Germany, and The Netherlands; see below.

THE FIRST DECADE OF ECIS

Contributions to the Como workshop in 1986 where ECIS was officially founded were collected in a new series of Progress in Colloid and Polymer Science named New Trends in in Colloid Science (https://www.springer.com/series/2882). This series of volumes was initiated by Heinz Hoffmann who also edited this first volume. The first ECIS conference in 1987 was documented in the same way in a volume edited by Vittorio Degiorgio and this tradition followed for many subsequent meetings. Partly because of the growth of ECIS meetings and the strongly increased number of contributions publications from recent meetings have been less systematic and spread over special issues of different journals like Journal of Molecular Liquids, Colloids and Surfaces A and B, Polymers and Nanomaterials.

From the start, ECIS conferences attracted wide participation from leading groups of chemists and physicists in several European countries, clearly demonstrating that the creation of ECIS filled a strong need. As mentioned, earlier ECIS conferences were well documented in New Trends in Colloid Science. From these we can infer a broad coverage of topics and an emphasis on fundamental aspects. Many early contributions concerned self-assembly in amphiphilic systems- surfactants, lipids, and block copolymers- but also processes at interfaces, and dispersions were well covered. With time a broader coverage of colloid and interface science, including biological aspects and applications, can be noticed.

The workshop in Como where ECIS was founded was attended by 100 scientists from 14 countries who presented 50 papers, most of them published in the volume edited by Heinz Hoffmann. The first ECIS conference (Como, 1987) was attended by 130 participants from 17 European countries who presented about 100 papers in oral and poster sessions; the largest groups of participants were from Italy, Germany, France, and Sweden. The scientific contents mainly covered colloids, amphiphile solutions and interfaces, with a majority in the field of the self-assembly of surfactants and other amphiphiles. The interest in ECIS increased strongly for the second conference (Arcachon, 1988) where there were 220 participants and more than 150 presentations with a broader scope. The subsequent meeting (Basel, 1989) attracted close to 250 participants who presented more than 100 papers in oral and poster sessions, again with a large part on the self-assembly in different colloidal systems. Coming back to Italy (Copanello, 1990) in the following meeting, the large interest continued, and the scope broadened; the conference saw more than 150 papers representing 21 countries; several contributions concerned biologically relevant systems and mixed colloids like polymer-surfactant systems. In the 1991 ECIS conference (Mainz) there were 300 participants representing 17 countries whereas the following meeting (Graz, 1992) attracted 284 participants from 28 countries. In Bristol 1993 there were 159 participants from 20 countries and in Montpellier 1994 nearly 300 participants giving 50 oral and more than 200 poster presentations. The ECIS conference in Barcelona in 1995 saw a new record participation (320 scientists from 30 countries) and 301 papers (70 oral and 231 poster presentations). The following meeting in Turku, Finland had 253 participants from 27 countries.

Participation in meetings depends on factors like the site, mainly attractiveness, accessibility and standing of colloid and interface science in the host country; it is natural that smaller countries in the outskirts of Europe have more difficulties in attracting a large number of participants. Another factor is the competition with other conferences; in years of the triannual IACIS conferences participation has generally been lower.

The organization of an ECIS conference is a demanding task requiring a lot of work. An important reason why the society has developed so well is the willingness of many members to host conferences. Thus, the General Assembly has always had a number of proposals to consider. Whereas the early conferences were mainly taking place in larger and central countries, progressively more meetings were held in smaller countries and in the outskirts of Europe, like Austria, Croatia, Ireland, Finland, Norway, Portugal, Poland, and Turkey. Despite sometimes a remote location, the participation in ECIS conferences has always been quite large: the Antalya meeting in 2009 had 400 participants in spite of the long trip for many. Clearly a central location and attractiveness of a city plays a role, as can be judged from the especially high numbers of the meetings in Prague in 2010 (600 participants) and Rome in 2016 (more than 800). In recent years there have been an increasing number of participants from outside Europe, in particular Japan, USA and Australia.

EVENTS FOR YOUNG SCIENTISTS

From the beginning an important aspect of ECIS was to promote the careers of young scientists; many Ph D students have given their first scientific presentations at ECIS conferences. By the initiation of the European Student Conferences, ECIS has broadened the participation of younger scientists. The 19th ESC Conference will be organized in Bordeaux in 2024. The student conferences are mainly organized and chaired by students and the attendance of senior scientists is limited. An important promoter of this ECIS activity is Brian Vincent in Bristol.

ESC conferences have been given as follows:

2024	Bordeaux, France
2022	Szeged, Hungary
2019	Varna, Bulgaria
2017	Firenze, Italy
2015	Krakow, Poland
2013	Potsdam, Germany
2011	Falkenberg, Sweden
2009	Almeria, Spain
2007	Ven (island), Sweden
2005	Biezenmortel, TheNetherlands
2003	Bristol, UK

An additional activity of ECIS, mainly for younger scientists, is the courses on different topics regularly held prior to the annual conferences. A large number of Ph D students participate every year.

AWARDS

When ECIS became well established and attracted leading scientists in the field the need to honor important contributions and careers arose naturally. Three awards to senior scientists have been established, the Solvay Award (from 2001), the Overbeek Gold Medal (from 2006) and the ECIS-Lyklema Prize (from 2020); in addition there are several awards to younger scientists for best oral and poster presentations. Lately these are offered by the Bulgarian Academy of Science (Exerowa-Platikanow award), the Enzo Ferroni Foundation (Ferroni award), the journal Substantia (ECIS-Substantia award), Elsevier (for poster), Polymer MDPI and the Royal Society of Chemistry (see the website of ECIS: www.ecis-web.eu).

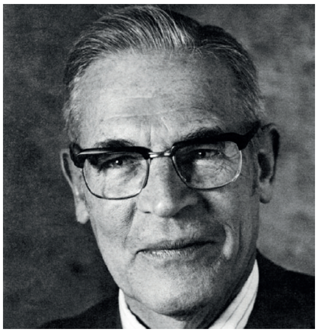

Figure 9. Theo Overbeek. Courtesy of ECIS.

In 2005 ECIS created the Overbeek Gold Medal to acknowledge excellent careers in, and inspiring contributions to, the field of colloid and interface science; it is named after Theo Overbeek a pioneer in colloid science. The prize is awarded annually. The Overbeek Medal is supported by the Overbeek Foundation, with donations from the Overbeek family as well as different partners, including Philips, Procter&Gamble, Nikko Chemical, DSM-Firmenich, Altana, BASF, AkzoNobel, Unilever, Albemarle, Shell, NanoScolo, Anton Paar, PTN and the Eindhoven University of Technology). The Overbeek Gold Medal honours leadership and scientific excellence in the field of colloid and interface science over an entire career. Hence the Overbeek Gold Medal recognizes extended periods of scientific excellence that have had an outstanding impact on this field. Recipients of the Overbeek Gold Medal have been

2024 Reinhard Strey (Cologne)
2023 Bernard P. Binks (Hull)
2022 Hans-Jürgen Butt (Mainz)
2021 Jacob Klein (Rehovot)
2020 Peter Schurtenberger (Lund)
2019 Yeshayahu Talmon (Haifa)
2018 Henk Lekkerkerker (Utrecht)
2017 Thomas Zemb (Marcoule)
2016 Piero Baglioni (Firenze)
2015 Mario Corti (Milano)
2014 Barry W. Ninham (Canberra)
2013 Otto Glatter (Graz)
2012 Dominique Langevin (Paris)
2011 Heinz Hoffmann (Bayreuth)
2010 Brian Vincent (Bristol)
2009 Gerard Fleer (Wageningen)
2008 Björn Lindman (Lund)
2007 Helmuth Möhwald (Golm)
2006 Håkan Wennerström (Lund)

Figure 10. Håkan Wennerström, first recipient of the Overbeek Gold Medal. Courtesy of ECIS.

Figure 11. Helmut Möhwald, ECIS conference organizer, president and second recipient of the Overbeek Gold Medal. Courtesy of ECIS.

Figure 12. In 2009 Gerhard Fleer (center) was awarded the Overbeek Gold Medal. Courtesy of ECIS.

The ECIS-Rhodia Prize was first awarded in 2001. After Solvay acquired Rhodia, since 2014 the official name of the prize has became "Colloid & Interface Science Award, sponsored by Solvay". This prize is granted to a European scientist for original scientific work of outstanding quality, described in one or several publications, patents or other documents made public in the previous five years. Hence, the prize is for recent work within the field of colloid and interface science. The recipients of the prize have been.

2024 Frieder Mugele (Twente)
2023 Regine von Klitzing (Darmstadt)
2022 Patrick Warren (Unilever)
2021 Jan Vermant (Zürich)
2020 Wilson C-K Poon (Edinburgh)
2019 Nikolai Denkov (Sofia)
2018 Horst Weller (Hamburg)
2017 Steven P. Armes (Sheffield)
2016 Shlomo Magdassi (Jerusalem)
2015 Julian Eastoe (Bristol)
2014 Helmut Cölfen (Konstanz)
2013 Luis M. Liz-Marzán (San Sebastián)
2012 Werner Kunz (Regensburg)
2011 Bernard P. Binks (Hull)
2010 Gero Decher (Strasbourg)
2009 George S. Attard (Southampton)
2008 Gordon J. Tiddy (Manchester)
2007 Peter Schurtenberger (Fribourg)
2006 Alfons van Blaaderen (Utrecht)
2005 Peter Pusey (Edinburgh)
2004 Thomas Zemb (Saclay)
2003 Henk Lekkerkerker (Utrecht)
2002 Piero Baglioni (Firenze)
2001 Kåre Larsson (Lund)

Figure 13. Dominique Langevin, president and only female recipient of the Overbeek Gold Medal. Courtesy of ECIS.

The ECIS-Lyklema Prize is named in honour of Johannes Lyklema, for his excellent science and leadership. The ECIS-Lyklema Prize is granted to an ECIS scientist with proven scientific excellence who additionally devoted long-time, sustained and exceptional efforts to ECIS organizational activities and colloid community development. The ECIS-Lyklema prize is awarded every 4-5 years and was given to Peter Kralchevsky in 2020. The second Lyklema prize has been awarded to Björn Lindman in 2024.

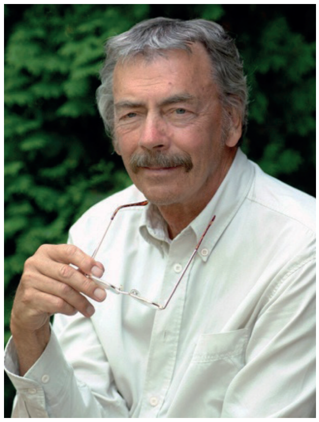

Figure 14. Kåre Larsson, first ECIS awardee (Rhodia prize, 2001). Courtesy of ECIS.

Figure 15. Peter Kralchevsky, secretary and recipient of the first ECIS-Lyklema Prize. Courtesy of ECIS.

In 2018 the European Colloid and Interface Society and the Department of Interfaces and Colloids in the Institute of Physical Chemistry of the Bulgarian Academy of Sciences created the Exerowa-Platikanov Award for a young scientist. The prize honours the long-term achievements of Dotchi Exerowa and Dimo Platikanov.

Figure 16. Dotchi Exerowa and Dimo Platikanov. Courtesy of ECIS.

CONCLUSION

The European Colloid and Interface Society quickly emerged as an important forum for creating interactions between scientists in a rapidly developing field. Not least has it helped younger scientists to get acquainted with the research frontier and to establish fruitful contacts beneficial for their careers. ECIS has involved essentially all of the European countries. The relevance of ECIS is demonstrated by the increasing number of participants in both regular conferences and in student conferences.

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