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Opinion Piece: *The Beauty and Pleasure of Understanding* Hugh Aldersey-Williams Igal Galili

The Hebrew University of Jerusalem, Israel

(Words of Introduction for the ESERA 2019 Meeting in Bologna)

Igal Galili studied physics in the former USSR and later at the Hebrew University of Jerusalem where he got his B.Sc, M.Sc.in physics and Ph.D. in theoretical physics. After his post-doctorate in the San Diego State University with Professor Fred Goldberg he became researcher in physics education and joined the staff of the science teaching department of the Hebrew University of Jerusalem.

He has published research papers in various educational journals *American Journal of Physics*, *International Journal of Science Education*, *Science Education* and *Science & Education*. And has developed a textbook in optics in broad cultural perspective that displayed the historical development of theories of light and vision from the ancient Greece to the modern physics.

I am greatly obliged to the organisers of this conference in Bologna for their invitation, especially in relation to the conference theme "The beauty and pleasure of understanding". I agree with the organisers that this theme is an expression of an essential aspect of science and thus also important for science education. I also agree that there are plenty of other important aspects of science and science education captured in the second part of the conference theme, "engaging with contemporary challenges through science education", an all-inclusive and popular claim about the significance of science education. Both parts are, of course, complementary.

The broad public recognises the existential need for science for our very survival, and to help us live effective and comfortable lives. Let us begin by noting these "pragmatic" benefits, listed in the lefthand column of Table 1. They are often sufficiently attractive to many students to interest them in science. Yet, the Bible hints at the fact that this list of benefits is incomplete; humans need more:

> Deuteronomy 8:3: …to teach you that man does not live on bread alone but on every word that comes from the mouth of the Lord.

Table 1. Pragmatic (left) versus Spiritual (right) benefits of science education

Science education…	Science education…
is required to develop, understand and use technology that promises to support personal and social well-being	provides an understanding of how Nature is organised as a whole, its law-like design, explaining "how it all works". This understanding is pleasing for its cosmic universal perspective (and is often poorly expressed as "fun").
enables reliable solving of problems across the great variety of human activities	reveals to students a special beauty of causal design, the architecture of Nature as theory based, an intellectual edifice of perfect harmony (aesthetic value). These aspects remain unknown to those who do not learn science.
stimulates development of individual skills and abilities, creativity, the art of logic	introduces students to the beautiful idea of unified, inductive and deductive logic by which an infinite variety of phenomena can be reduced to a few governing principles. That is to say science expresses the amazing unity across variety and variety in unity.
familiarises students with the rules of effective activity and knowledge that are objective and rational. It stimulates students' critical thinking, being responsible, cooperative, modest, open to criticism.	provides its students with intellectual depth, appreciation of sophisticated symmetry, the fundamental complementarity and parsimony in our grasp of reality
is faithful to science's aspiration to objectivity, offers a universal picture of the world	through historical examples, promotes the non-pragmatic values of altruism, romanticism, devotion to the needs of society, learning from others.
provides a solid basis for individual prosperity, social respect, and successful careers	
introduces ethical norms of social behaviour and rules of productive cooperation	

In the righthand column of Table 1, I tried to enumerate benefits of another kind that could be considered "spiritual". While they may appear more esoteric, I argue they actually encourage us to construe science as its own distinctive cultural. This distinguishes science from a craft that has specific rules that must be followed to be successful.

The pragmatic claims in the left-hand column are taken for granted and commonplace. Their objective validity draws on the great achievements of our society. The "spiritual" features in the right-hand column, however, are often considered to

be emotional and illusive and therefore, optional, subjective, secondary, causing merely affective impact that may enhance the effect of teaching but dilutes, misleads and detracts attention from the "true" content of science learning, and results in the loss of valuable time.

Let me begin my argument by observing that science itself did not start for the purpose of providing practical benefits. Science started with searching for objective causes of natural phenomena, law-like regularities, and then introducing abstract concepts and models of the natural order. Rational objective knowledge – *episteme* – was invented in Classical Greece. There was no obvious need to do that since technological knowledge – *techne* – was not immediately related to natural philosophy. Why know about the arrangements of stars and planets in multiple spheres with complex structure? Why know about "effective" causes for seasons and the mechanism behind their cycle? Why know about elements and structure of matter? Why know how vision works? Yet, these and other questions about reality emerged very early and continue to provoke people through the ages without immediate and obvious practical benefits.

Skipping a comprehensive analysis, we may listen to the scientists themselves[1] who, from the dawn of science, continuously addressed their drive, motivation and intention. For example, in modern times, this is how James Peebles, who won the Nobel Prize in physics in 2019, reacted to the announcement:

> The prizes and awards, they are charming, much appreciated, but that's not part of your plans. You should enter science because you are fascinated by it.

"Prizes" can be understood in a broader sense as practical benefits. Scientists continuously repeat the idea which Leonardo expressed as: *The noblest pleasure is the joy of understanding.*

The renowned scientist of the recent past, Henry Poincaré (1908), refined it while reflecting on the history of science:

> The scientist does not study nature because it is useful to do so. He studies it because he takes pleasure in it, and he takes pleasure in it because it is beautiful. If nature were not beautiful it would not be worth knowing, and life would not be worth living. (p. 22)
>
> Is it merely that things which seem to us beautiful are those which are best adapted to our intelligence, and that consequently they are at the same time the tools that intelligence knows best how to handle? (p. 23)
>
> …the Greeks loved the intellectual beauty hidden behind sensible beauty, and that it is this beauty which gives certainty and strength to the intelligence. (p. 24)

The history of science abounds with such confessions emphasising the pleasure of understanding as a special type of emotional excitement caused by revealing the special type of beauty the world possesses. Thus, pleasure and beauty are components of science as practiced. But are they essential? Let us proceed.

For centuries, the concept of beauty has been considered emblematic of Italian culture. Beauty attracts people universally; including beauty as revealed through science. But this reaches a level of refinement in Italy, in particular, that is noteworthy. Consider Florence, the place where people especially venerated beauty. In the

[1] "To learn from the horse mouth" (Wong & Hodson, 2009).

16th century, they placed the statue of David by Michelangelo in the central square of the city as a symbol of beauty (Fig. 1a). It stays there now – a lovely young fighter of perfect proportions. Yet, the youth was neither Apollo nor Alexander the Great, but the Biblical hero, King David.

What is remarkable about this choice is the fusion of a warrior, demonstrating the power of force, courage and devotion to his people with something very different. David was a poet whose poetry, *The Book of Psalms*, talking to and about God, has been in continuous use for three thousand years by people around the world in their everyday prayers. David apparently symbolised the symbiosis of internal and external beauty in ultimate harmony which seemingly left no place to add anything else. Was it so?

In fact, the people of Bologna did not agree with Florence and pointed to another dimension of beauty missing in the Florencian set – the beauty and pleasure of understanding, not less and possibly more divine in its nature. In the 11th century, the people of Bologna established a new type of temple, the temple of knowledge, the university – *Alma Mater Studiorum*. Their heroes were people of knowledge and understanding: students and professors. Within the national tradition of artistic visualisation, they produced the image of a student (Fig. 1b). In parallel to David, a young warrior-poet and emblem of the beautiful inside and out, the figure of the young student is delighted by the knowledge revealed to him; this became emblematic of Bologna. It is this image that we may consider as a visualisation of the title of our conference – *The beauty and pleasure of understanding*.

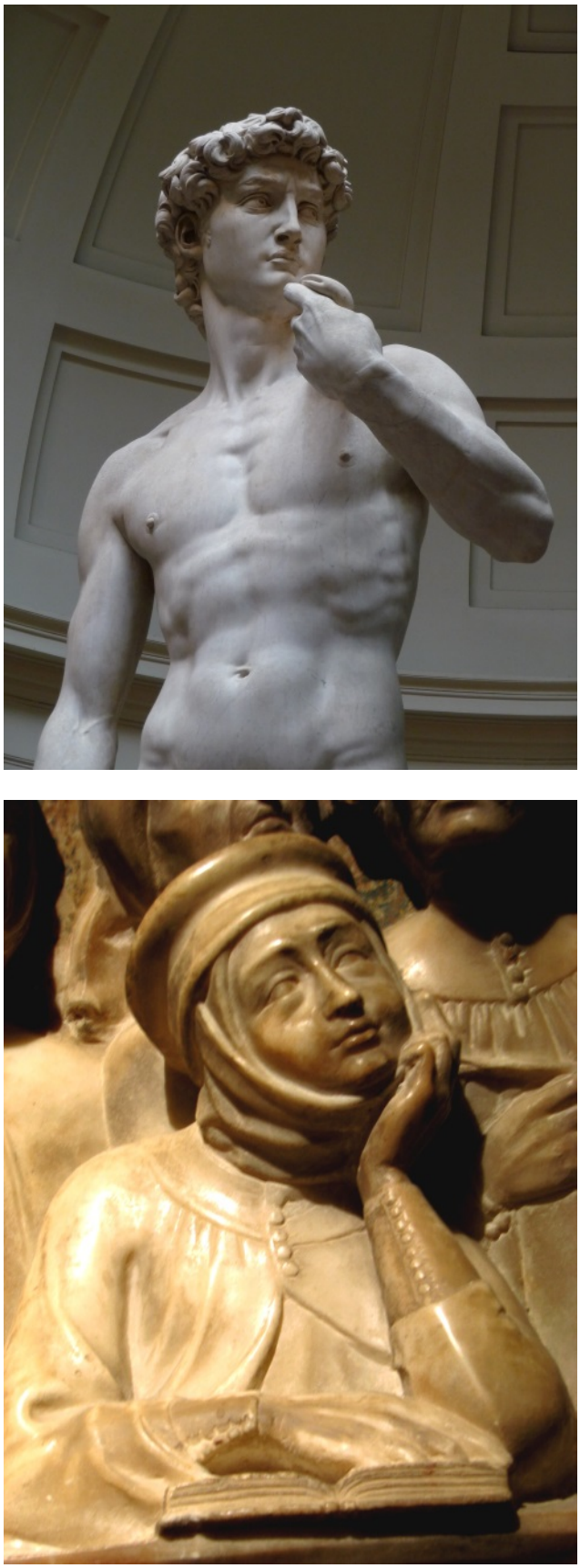

Figure 1. (a) A fragment of the statue of David by Michelangelo (c. 1504) in Florence. (b) A fragment from the bas-relief on the sarcophagi of a professor in Bologna University by Masegne (c.

1383).

Over the course of one thousand years, this university was decorated by a long gallery of renowned scholars of which I mention a few whose names I encountered: Giovanni di Casali, Giovanni Battista Riccioli, Francesco Maria Grimaldi, Giovanni Domenico Cassini, Luigi Galvani, Guglielmo Giovanni Maria Marconi and of course, Umberto Eco. They all illuminated the minds of numerous students who were introduced here to the unique beauty and pleasure of understanding. In line with this tradition, in 2002, the journal *Physics World* announced the choice made by its readers to consider the physics experiment performed in 1974 by three Bologna professors (Pier Giorgio Merli, Gian Franco Missiroli, and Giulio Pozzi) as the most…beautiful of all time. From all the possible characteristics that could be used to describe scientific products, a rather unusual description, "beautiful", was chosen for the experiment providing evidence of the amazing interference of an electron with…itself.

As we turn to science education, it is my special pleasure to pay tribute to University of Bologna professor Nella Grimelini-Tomasini (Lella) who has raised the flag of the *Pleasure of Understanding* in physics education. Many people certainly join me now in sending her our deep appreciation, sincere gratitude and wishes of health and prosperity that she so much deserves.

It seems to me that the location of this meeting and the idea of highlighting the "spiritual" aspects of science education, which was made explicit in the title of our meeting, is as surprising as blossoms in springtime. It is therefore paramount to capture this moment and draw attention to the importance of encouraging this perspective in science education[2]. This spiritual commitment of the physics education group in Bologna (established by Lella) encourage us to explore this intellectual direction in science education. They have raised the flag however, profound questions emerged regarding its implications. What should we actually do to encourage students to experience the pleasure of understanding of science? What content should we specifically address? Is there something teachers can do in addressing this content beyond the general claims of Table 1?

We need to show that even if pragmatic values may prevail for their existential benefits, their spiritual extensions are vital for science *understanding*. Such recognition cannot be spontaneous or intuitive. It requires clarification and specific restructuring of numerous curricular components

[2]It is a pleasure to mention the students and colleagues of Lella whom I had the honour to cooperate with in research: Olivia Levrini, Barbara Pecori, Marta Gagliardi, Eugenio Bertozzi, Paola Fantini, Giulia Tasquier.

[3]Tseitlin & Galili (2005, 2006), Levrini et al. (2014), Galili (2017)

and their underpinnings be they disciplinary, cognitive, philosophical, historical and sociological, which all contribute to our understanding of understanding. What should be included and how? To provide my answer, let me briefly present results of a comprehensive study dealing with this topic[3]. This line of work suggested a special organisation of the science curriculum, which I call *discipline-culture*. Within this perspective, I intend to answer those questions raised above.

Scientific knowledge is comprised of big clusters of knowledge elements which are internally coherent. These clusters can be structured and hierarchically ordered. The elements of each cluster share a certain historical thread, methodological tools of production of new elements, adopting some and rejecting others. They create a colony or a culture. These groups comprise the fundamental theories known to us, each providing a specific picture of the world (mechanics, electromagnetism, quantum, etc.). One may imagine science as a polyphony of different perspectives on Nature, together comprising the Book of Nature as Galileo put it. In a sense, the situation can be well animated by the artistic image of angels singing in divine, but different, voices from the same book (Fig. 2). Scientific theories create a family of cognate knowledge systems describing nature. They share certain concepts and differ in others[4]. We may identify this dialogue of theories as a special culture – the culture of science[5].

Furthermore, the traditional disciplinary perspective considers a scientific theory to be structured by its nucleus (fundamental principles, concepts, paradigmatic model) and its body (derivations, implications, working models, conceptions, experiments) coherent with the nucleus. The discipline-culture perspective upgrades the disciplinary perspective with the third type of knowledge elements, the periphery. The latter includes elements sometimes at odds with the nucleus, representing open problems, competitive principles and accounts by other theories. In this way, a culture includes the potential to change itself. In a way, the presented approach bridges the opposition between discipline and culture as defined by Kant in 1781.

Figure 2. Singing angels from the Ghent Altarpiece (c. 1432) by van Eyck brothers

My colleagues and I have argued that the obtained triadic structure, nucleus-body-periphery, is more

[4]The idea of family resemblance is due to L. Wittgenstein, while the many-faceted somewhat contradictive accounts of nature in the discourse regarding the world may remind the idea of carnival by M. Bakhtin in his literature critique.

[5]The concept of culture ascribed to a family of fundamental theories may remind the culture used in biology to designate a colony of micro-organisms of the same kind.

faithful to the reality of knowledge exploration. It also happens to be effective in representing scientific knowledge in the context of education.

This discipline-culture perspective implies a pertinent restructuring of introductory curricula. It will emphasise principles, connect them to phenomena and guide the construction of explanations beyond technical manipulation. It will encourage us to make explicit the limits of the validity of each theory by pointing to alternative accounts, either correct (from the more advanced theories) or wrong (from the rejected theories). For instance, the ideas of mechanics of Aristotle, Einstein and Bohr all appear in the periphery of the theory in which the nucleus incorporates the Newtonian laws of motion. The triadic identification of curricular elements can match variation in the interests, skills and preferences students naturally display, expanding their willingness to learn and explore. Being exposed to the subject matter of all three aspects, each individual combines his/her interests in different proportions of efforts and desire.

Thus, in Figure 2, the first group of students shows a special interest to the nucleus, the theoretical paradigm. These students are interested in the big ideas, and they take a holistic perspective on what that theory tells us about the world, a kind of philosophical standpoint. They are not much interested in solving standard problems. They easily decide to leave that to others and rely on scientists to justify this knowledge. It looks as if such students ask us "Show me God", the overall design of the world. Einstein, Newton, Kepler, Aristotle shared the same focus in their interest with respect to understanding. In a sense, we could call such students "philosophers".

In contrast, the second group shows interest and readiness to deal primarily with concrete problems, mastering the power of control over nature, and seeking immediate benefits. They show much less interest in the justification of the principles used as long as they help them to reach the goal. They are interested in the *body* knowledge as a tool box for experimenting, solving new problems, realisation of knowledge potential. Using simplified examples: understanding and addressing climate change – yes; the analysis of the nature of inertia and principle of equivalence (as interested Mach and Einstein) – no. In a sense, we may call these students "practitioners".

Finally, the students of the third group take a sort of critical stance. They question the claims of the nucleus: "Why these principles not the others? Where did you get them from? Was there any choice?" This was Einstein's and Leibnitz' interest. "Are these principles universal, unique, applied outside of science? Where do these laws fail?" If we, as their teachers, ignore this kind of questions, those students are disappointed and lose their interest: "I do not like science, I prefer something more human…" They may dream easily, miss their teacher's instructions, and fail on exams. They "do not care" and could be "trouble-makers" in class. They could be referred to as – "revolutionaries". This all may change if the teacher addresses the *periphery*. We may, then, observe a radical change in their attitude and witness them joining the rest of the class equipped with a different motivation.

As to the attitude of science teachers, they often ironically patronise the "philosophers" trying to encourage them to be more serious, invest more effort…We are often satisfied with the "practitioners" and usually provide them with all available support. As for the "revolutionaries" (who loves trouble makers?!), they disturb the smoothness of lecturing. Their questions may puzzle us and they

might expose us unprepared. We call them to order, trying to explain that such questions lead us astray, impede understanding, break the thread of explanation and take time away from what they need most training in. We may promise answers in some unclear future, just not now.

These are contrasting preferences and each individual combines all three of them in some proportions. Looking back over my own experience in teaching introductory physics courses for many years, I may mention that the students who identify strongly as "philosophers" usually became scientifically literate, enlightened citizens able to consider problems of the society saturated with scientific content. The students whom we identified as "practitioners" normally became involved in technology and applied sciences and medicine. They became proficient consumers of science, "normal" explorers (Kuhn called them "puzzle resolvers"). As to the "trouble-makers", some of them indeed switched to humanities and activities outside of science, but there were a few among them, who proceeded to higher degrees and joined the researchers at the frontiers of science and high-tech. These were the students who produced new knowledge (Kuhnian "revolutionaries").

In any case, I do not intend to create a fully deterministic picture, but just to share my experience. Reading the memoirs of scientists, especially those known for their contributions to modern science (e.g. Galileo, Heisenberg, Einstein, Poincare, Weinberg), may provide additional support to this three-part perspective on a scientific theory as a *discipline-culture*.

I return now to the question how science teaching can stimulate, encourage and instigate the perception of pleasure in understanding and a sense of the beauty of science and scientific knowledge. For that, we need to recognise the structure of science as a culture and recognise the preferences in the non-homogeneous population of students at schools and universities. Accordingly, our curricula and teachers should talk in three voices addressing the nucleus, body and periphery of the theories considered. This equally addresses ontological (content) and epistemological (methodology) aspects. The new approach discharges the claim of "two cultures" (science versus humanities) (Snow, 1959) which implied a simple dichotomy of students, good and bad at science. The reality is much richer and more interesting, allowing a wider population to enjoy learning science.

Cognitive resonance between the emphasis of instruction with their intellectual preferences will allow students to enjoy science class, appreciate the beauty of scientific knowledge and identify their own areas of interest. This approach involves various aspects of the humanities (epistemology, logic, history, aesthetics, world view) intertwined with the science content; an approach that will help more of our students have deep experiences of pleasure in understanding. This approach suggests a framework for addressing the dual nature of science mentioned in Table 1. The enjoyment of learning cannot be of the same kind for all, and it is not unique for each.

A final comment on the colloquial claim "Science is fun". Its rather uncertain meaning may easily miss the intellectual depth of *the pleasure of understanding science*. "Fun" has the connotation of being light, amusing, superficial, and fleeting, which poorly matches being analytic, appreciating aesthetics, and delighting in the beauty of science and experiencing pleasure with the understanding of complexity. Though there is no need to engage in a crusade against casual "fun", it would be

good if a teacher who proclaims that "Science is fun!" is aware of what is deeply enjoyable about science that is not captured by this phrase (similar to us when enjoying cola not forgetting about good wine).

I conclude with the belief that the paradigm of *discipline-culture*, by revealing the structure of scientific knowledge, the nature of knowledge elements and scientific dialogue, can transform the *pressure for understanding* to the *pleasure of understanding* of science. It creates a bridge between the realms of science (related to objective pragmatic benefits) and the humanities (related to subjective and spiritual values) often perceived to be in opposition. Understanding the formal disciplinary content does not exclude but is enormously enriched by the relevant philosophical background. Together, they result in the pleasure of understanding science. Indeed, science can bring fun, but mainly, it can enrich us with much more – *the pleasure of understanding* which is a serious business, because it reveals us the genus of science, and this is truly exciting.

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