Einstein's Wonder*

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Abstract: In his Autobiographical Notes Einstein recognizes the importance of wonder in the cognitive process by stating that it occurs when an experience comes into conflict with a sufficiently stable world of concepts. Already in classical philosophy, wonder is considered the starting point of philosophizing as Plato highlights in *Theaetetus* and Aristotle in *Metaphysics*. To describe what the wonder consists of we will suggest a Dynamic Frames and we will use it to describe the role of wonder in the years of Einstein's formation.

Keywords: Einstein, Wonder, Dynamic Frame.

1. Dynamic Frames

Dynamic Frames were introduced in the field of Cognitive Psychology (Barsalou 1992; Barsalou, Hale 1993) and represent a structure of knowledge expressed in a concise form that involves conceptual and empirical aspects. They have been used fruitfully in Philosophy of Science to analyze scientific concepts (Kornmesser 2018) and conceptual change (Andersen et al. 2006).

A Dynamic Frame can be defined as a matrix of attributes and values that characterize a concept. A typical example is the Dynamic Frame associated with the concept of '*bird*', whose graphic representation is:

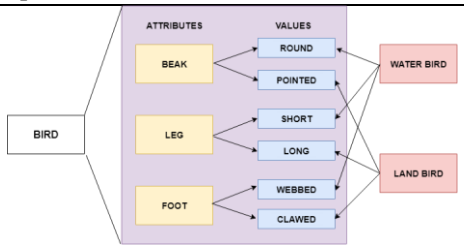

Fig. 1. Dynamic Frame for 'bird' concept

The leftmost element of Fig.1 is the bird concept which takes the name of "*superodinate concept*"; in the central pane there are the bird's attributes {beak, leg, foot} and the values associated with them[1]. The last column of the diagram corresponds to the "*subordinate concepts*" – or derived concepts – which are a specialization of the main concept and activate only certain values[2]. The activation functions of the values that determine the subordinate concepts are called "*determination links*"[3].

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[1] In Fig. 1 for example the beak attribute has the values {round, pointed}.

[2] In the example of Fig. 1 the subordinate concepts are "water bird" and "land bird".

[3] In the example of Fig. 1 the determination links are the arrows that start from subordinate concepts.

Once we have defined what a Dynamic Frame consists of, our task moves on to define what are the attributes, values and subordinate concepts of wonder.

2. Wonder

The study of wonder has a long history and has its origins in Greek philosophy. The corresponding Greek term is "*Thaumazein*" and has its roots in Greek mythology, in the Thaumas deity that represents the wonder and dangers of the sea. The sea is a place that does not belong to man and the wonder comes from this world that is unknown. Thaumas is a deity who does not belong to the chaotic period of Chronos and Gaia nor to the partially ordered world of Zeus and Poseidon: *Thaumazein* therefore represents an experience that is not chaos, but not even order; it is the acknowledgment of a hidden - unreachable - order that lies below appearances.[4]

In Homer (Neightingale 2001) and in archaic literature the term has both a cognitive and emotional value, with a meaning that involves the feelings of reverence, awe and admiration. The term is also used with this meaning by Plato in the myth of the cave, where the activity of philosophizing is traced back to the contemplative observation of an ideal world; at the sight of the ideas the philosopher is amazed, he experiences a silent wonder accompanied by a feeling of beauty.

We are therefore faced with an emotion that is suffered, in principle 'positive', and which represents the reaction of the human being in the face of something that goes beyond his abilities and knowledge.

The characteristics just highlighted have also been found in cognitive psychology which in recent years has focused on the study of awe. Awe and wonder have similar characteristics and according to Gallagher et al (2015) the second is a complex emotion whose initial stage is the first one. Wonder thus becomes a more reflective - or second-order - emotion as also indicated by Fuller (2015) and Matravers (2015).

To understand which features are essential for the emotion we are studying, the contribution of Keltner and Haidt (2003) is important, because they propose - through a prototype approach - two essential attributes:

a. the elicitor factor of the emotion: 'perceived vastness'.
b. the cognitive consequence: 'need for accommodation'.

The perception of vastness is a typical factor that generates wonder; every time we are faced with something that physically has a much greater dimension than 'the self' there is the possibility that our emotional experience coincides with wonder. For example, consider the emotion of wonder associated with the view of the starry vault, of natural landscapes such as the earth from space (Gallagher 2015) or of large architectural structures. In a following article (Shiota et al 2007) it is shown how the idea of 'vastness' is not only linked to the perception of something physically larger than us but also how "one may experience a sense of vastness in a mathematical equation, not be-

[4] It is Iris - the rainbow in Greek mythology, messenger of the gods and daughter of Thaumas - who brings this message to man.

cause the equation is literally long, but because of the vast number of observed physical processes it is able to explain and predict" (Shiota et al 2007). Therefore, one can also be amazed by the power and richness of a mathematical theory.

The second attribute - the cognitive consequence of emotion - is represented by the "*need for accommodation*" which refers to Piaget's theory of cognitive development in children. Faced with a new experience, the child seeks first of all to include the new experience in the conceptual structures available to him; if this process leads to a positive outcome, the experience is assimilated into the conceptual baggage (assimilation). If, on the other hand, the new experience remains unexplained, a new process comes into play which takes the name of accommodation; in this case the child tries to restructure his conceptual framework to include the new experience. In Gallagher et al (2015) the wonder is characterized precisely by this aspect, as evidenced by its definition: "A reflective feeling one has when unable to put things back into familiar conceptual framework".

We have therefore come to identify an emotion characterized by two specific attributes; in fact it manifests itself in the face of the perception of something incommensurable with respect to us or to our abilities (elicitor factor) and also requires a profound modification of our conceptual framework (cognitive consequence). This type of wonder is called 'contemplating wonder'.

However, there is another type of wonder that the Greek philosophers had already identified. Plato in Theaetetus was the first to make philosophy descend from wonder by affirming: "[...] for wonder is the feeling of a philosopher, and philosophy begins in wonder" (Plato 2015, Theaet. 155d2-4). But what wonder is it? Is it perhaps the contemplative one that the philosopher feels in front of the world of ideas in the myth of the cave? According to Plato it is a different emotion, in fact Theaetetus describes this emotional state as a disorienting emotion - you feel dizzy - that arises from a deep bewilderment. But where does this bewilderment come from? It is Aristotle who describes with greater precision how this emotion arises.[5] In the Metaphysics the Stagirite emphasizes that:

> [...] all men begin, as we said, by wondering that things are as they are: as they do about [...] the incommensurability of the diagonal of a square with the side: for it seems wonderful […] that there is a thing which cannot be measured even by the smallest unit. But we must end in the contrary […] state; for there is nothing which would surprise a geometer so much as if the diagonal turned out to be commensurable (Aristotle 1991, Met. 983a, 11-20).

Referring to the attributes previously identified, the wonder arises - elicitor factor - from a conceptual contradiction (the incommensurability of the diagonal of the square) and induces - cognitive consequence - a process of accommodation. This type of wonder is called 'questioning wonder'.

[5] Aristotle also derives philosophy from wonder; in the Metaphysics he states "For it is owing to their wonder that men both now begin and at first began to philosophize" (Aristotle 1991, Met. 983a, 11-20)

It is important to underline that Aristotle's observations show us how this type of wonder manifests itself in the process of acquiring knowledge, just as it is highlighted in recent studies on the role of epistemic emotions in the learning development (see for example Muis et al (2015)). Along this line of research is also the work of Zazkis, Zazkis (2014) who studies how wonder can influence the study of mathematics. He identifies the two types of wonder starting from the analysis of the verb 'wonder'[6] and then underlines some themes that can favor wonder. Among them we remember the perception of something magical (eg algebraic games) and counterintuitive results (eg the fact that regular polygons are infinite while regular polyhedra are reduced only to Platonic solids). Wonder always comes from a profound contradiction with respect to a conceptual framework that generates expectations; it is the incongruity with respect to expectations that causes wonder and leads us to seek a solution. The most appropriate term for these inconsistencies is the Greek term ‘aporia’, that we use in the following.

In conclusion, we can come back to the definition of a Dynamic Frame for wonder and establish that the fundamental attributes that identify emotion are the 'elicitor factor' with the values {'vastness'; 'aporia'} and the 'cognitive consequence' which assumes the only value {'need accommodation}. There are also ‘contemplating wonder’ and ‘questioning wonder’ as subordinate concepts. The graphic representation of the Dynamic Frame is as follows:

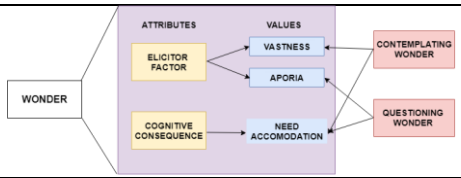

Fig. 2. Dynamic Frame for ‘wonder’ concept

3. Einstein’s Wonder

If we retrace the years of the formation of the young Einstein we discover he had a first period of religious fervor which was followed by a second more purely scientific one as he realized that:

> Out yonder there was this huge world […] which stands before us like a great eternal riddle […]. The contemplation of this world beckoned like a liberation [...] The mental grasp of this extra-personal world within the frame of our given capacities presented itself […] as the highest goal. (Einstein 1951, p. 5)

In this passage the emotion of contemplative wonder is evident, in fact Einstein observes with admiration a world that is given to us in its vastness and designs an intellectual path in order to possess it entirely (need for accommodation).

[6]The contemplating wonder is linked to the use of the expression "wondering at", while the questioning wonder is associated with the use of 'wondering how / why ".

Continuing in the description of how thought is implemented, Einstein comes to considerations similar to those set out for the concept of questioning wonder. In fact, he says that the wonder comes from the incessant process of conceptual connection produced by our thought and occurs

> when an experience comes into conflict with a world of concepts which is already sufficiently fixed in us. Whenever such a conflict is experienced hard and intensively it reacts back upon our thought world in a decisive way. (Einstein 1951, p. 9)

The conflict must be resolved, in such a way that the intellectual world we have developed is able to understand even the contradictory experience; we are faced with a learning process triggered by an 'aporia' that leads to an attempt at accommodation.

Einstein states that he felt a similar wonder at the age of 4/5 when his father showed him a compass. "That this needle behaved in such a determined way did not at all fit into the nature of events, which could find a place in the unconscious world of concepts (effect connected with direct 'touch')" (Einstein 1951, p. 9). This experience made a lasting and profound impression on him as it represented a new and contradictory fact with respect to the conceptual structure it possessed at that time. Failing to include the compass experience in his conceptual world, Einstein realized that in this experience there was something "deeply hidden" that aroused his wonder and that had to be brought to light.

An emotion of wonder was experienced by Einstein even at the age of 12 while reading a book of geometry[7]. The wonder arose from the observation that some completely evident concepts, such as the basic ones of geometry (the line, the point ...) had an immediate confirmation in the experience (the rigid rod, the finite interval ...) and through them a certain knowledge could be built by means of pure thought. How to define this wonder? The elicitor factor seems to be the 'vastness' found in the ability of mathematics to describe the world, just as indicated by Shiota et al (2007), and the cognitive consequence is the drastic conceptual change that leads him to direct his own 'existential' need of world knowledge towards mathematics. At the end we can think Einstein felt a contemplating wonder.

The wonder in the young Einstein was stimulated by numerous readings, among which the popular books of Natural Science by Bernstein (Gregory 2000) must be remembered. Bernstein's style was very distinctive in that it emphasized the wonder and awe at the scientific achievements of the 19th century. He proposed to the reader to analyze situations that are not found in everyday life[8] and stimulated the sense of magic and the 'hidden' when he observed how nature hides itself from our eyes[9]. Questions and observations of this type are the same highlighted by Zazkis, Zazkis (2015) and it

[7] Einstein said that this type of wonder is "of a totally different nature" (Einstein 1951, p. 9).
[8] For example, he wondered what the world and knowledge of it would be like if man had not the sense of sight.
[9] Bernstein admitted the existence of hidden forces such as those that hold atoms together.

shows how questioning wonder is induced by them, stimulating in this manner the learning process.

That the readings of Bernstein's books were important for the young Einstein is also confirmed by the analogy that exists between Bernstein's proposal to undertake a fantastic journey inside a telegraph cable and the famous thought experiment of the light beam (Kaku 2004). Einstein - around the age of 14 - imagined himself running alongside a light beam and asked himself the question of what the light beam looked like in this situation; the electromagnetic wave should have been crystallized and not oscillate over time. The conclusion reached by Einstein was that a similar situation was not acceptable because nor based on experience nor was it justified by Maxwell's equations. To better understand the emotional state of the German scientist, it is useful the 1916 interview given to Wertheimer in which the thought experiment is described. Einstein underline how "The process started in a way not very clear, and is therefore difficult to describe - in a certain state of being puzzled" (Norton 2013, p.131). He proceeds by asking a series of questions - "[…] What if one were to run after a ray of light? What if one were riding on the beam? [..] If one were to run fast enough, would it no longer move at all?" (Norton 2013, p.131) - that circumscribe the problem from a physical point of view and explore the conceptual framework of classical physics, showing its difficulties and inconsistencies. There is therefore an attempt to assimilate the experience into classical physics which, however, does not conclude itself positively. The difficulties encountered generate doubts ("Later developments increased this doubt" (Norton 2013, p.131)) and confusion, leading Einstein to undertake a process of accommodation of classical physics that will end with the formulation of Special Relativity.

4. Conclusions

In this article we have presented a Dynamic Frame for wonder, identifying the derived concepts of contemplating and questioning wonder which we later applied to the study of wonder in the formative years of the young Einstein.

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