The sounds of war: 'phonotelemetry' at the Italian front

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The sounds of war: "phonotelemetry" at the Italian Front

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Abstract

This paper is devoted to a historical research on a sound ranging technique, called "Garbasso-Cardani method", which was developed in Italy during the years of the Great War (1915-1918). Such a method, that was aimed at detecting the location of the enemy artillery positions upon the basis of the sound produced by the artillery gunfire, proved crucial during the battles of the Italian Front at the border between the Austro-Hungarian Empire and the Italy. This research, which is largely based on archival documents, led to an exhibition including interactive experiments on the physics of sound and a battlefield model. Case-studies like this one might be helpful in guiding physics teachers to establish a more active classroom environment.

Keywords: history of physics; physics education; Great War; sound ranging

Introduction

One of the cornerstones of science education research is the study of the role of history of science to inspire young generations to enrol in science and mathematics classes and to help students to achieve a successful learning outcome while studying science (e.g. [1][2]). By leveraging on the possible contributions of history of physics to physics education, it is here presented an historical case-study, largely based upon original archive materials, that might be helpful in guiding teachers to establish a more active classroom environment.

This case-study concerns the scientific contributions given by physicists – and, in particular, by Italian physicists – to the Great War, this year marking the 100th anniversary of its end. Our research is especially devoted to a method for detecting the location of the enemy artillery positions, upon the basis of the sound produced by the artillery gunfire, that proved to be of primary importance during the battles of the Italian Front at the border between the Austro-Hungarian Empire and the Italy. This sound-ranging technique was called in Italy *phonotelemetry*, *phono* (sound) – *tele* (at a distance) – *metry* (measurement), that is transmission of data from a remote source by an acoustic method.

This method contains plenty of physics and was the subject of a successful exhibition held in early 2016 in Parma, Italy, aimed at students of upper secondary school.

Physicists and Great War: the Italian case

As is well known, the Great War was an international conflict that lasted from 28 July 1914 to 11 November 1918, and that involved most of the nations of Europe, Russia, the United States, the Middle East, and other regions. Italy entered the war on 24 May 1915 alongside the Allied Powers (Great Britain and the British Empire, France and the Russian Empire) against the Central Powers (Germany, Austria-Hungary and Turkey).

The Great war, unlike earlier wars, was strongly driven by the development of new technologies, e.g. in communications (wireless telegraphy allowed communications at sea and in the air and coordination between mobile units during battle), and the introduction or improvement of weapons such as submarines, warplanes and tanks. Just as the scientific-technological warfare efforts became essential and decisive, so also the role of scientists and technologists became crucial through the invention of new devices, the development of new technologies and the organization of new services.

As for Italy, the analysis of archival documents and other primary sources highlights that during the Great War many – nationally and internationally well-known – Italian physicists temporarily left their respective research fields to devote themselves to research and activities related to war, even to enlist as volunteers. They contributed to a wide range of technologies, at times with desk research, but very often with field studies: from the creation of new radiotelegraph systems specifically designed for the Army and the Navy (the research of the Nobel Prize Guglielmo Marconi on the transmission with short waves) to ballistics studies in reference to issues related to aircraft and anti-aircraft artillery (experiences on airships by Vito Volterra); from research aimed at the construction of hydrophones for the acoustic detection of submarines (the "C pipe" by Antonino Lo Surdo) to sound studies with the creation of new equipment for the detection of the position of enemy artillery (the "phonotelemetric method", devised by Antonio Garbasso and Pietro Cardani). It is just this latest issue, the acoustical detection of enemy artillery through a sound-ranging technique, the main focus of our analysis (for a preliminary account see [3]).

Antonio Garbasso, Pietro Cardani and the phonotelemetry

A crucial problem, faced since the beginning of the war, which was essentially a position war, fought largely in the trenches, was to develop a method to detect the position of the enemy artillery, e.g. a cannon, on the basis of the sound that was emitted at the time of the shot – the "cannon shot" – without being able to see the glare provoked.

The acoustic phenomenon of the cannon shot is very complex: for bullets that go at a speed higher than that of sound, the "muzzle wave", ie the wave that is produced at the exit of the projectile from the muzzle of the cannon, is superimposed to the "ballistic wave", that is the wave produced by the supersonic motion of the projectile through the air. Actually, only the muzzle wave is of interest because it is the one that gives the position of the cannon. It is therefore necessary to isolate the muzzle from the ballistic wave. To do this, however, in-depth studies on the physics of sound are required. Foremost among those contributing to this research had been two Italian physicists: Antonio Garbasso (1871-1933) and Pietro Cardani (1858-1924).

At that time, Garbasso, who was professor of Experimental Physics at the University of Florence and Director of the *Regio Istituto di Studi Superiori* in Florence (Royal Institute of Higher Studies), was a well-known expert of spectroscopy and to him was due one of the first attempts to deal with the Stark effect in terms of Bohr's theory [4]. On July 18, 1915 Garbasso volunteered in the Army and was appointed Lieutenant of the 3rd Regiment Genio (Army Corps of Engineers). He was initially assigned to a "commission for studying certain bright bombs, which should have served to illuminate the ground in front of the trenches, to prevent possible nocturnal attacks".

Just ten days later, on July 29, 1915 Garbasso wrote to Vito Volterra (a famous mathematical physicist who had also enlisted as a volunteer), with whom he will be in close correspondence throughout the war: "What has emerged is a curious matter of spectroscopy, which I hope to solve in a simple and practical way. I am so pleased to think that what has been done in the past can now serve the good cause" [5].

Fig. 1 – A. Garbasso in uniform of Tenent of the Army Corps of Genio (Fondo Garbasso, Osservatorio Astrofisico di Arcetri)

Pietro Cardani, Professor of Experimental Physics, Director of the Institute of Physics, Rector of the Royal University of Parma (1914-1919) and former Deputy during the 22nd and 23rd legislatures of the Kingdom of Italy (1904-1913), also enrolled as a volunteer to the Army Corps of Engineers and assigned to the same Depot of the Regiment as Garbasso [6]. As Garbasso will later write in a book partly devoted to the "phonotelemetry", while he was at the Depot,

> [I] learned from a Captain who had been in France [that] the French tried to determine the position of masked batteries by an acoustic method. [This] thing seemed to some far-

fetched; it seemed less absurd to me and to some others because we realized that the solution to the problem, at least from a theoretical point of view, was already implicitly contained in the classical geometry of the Greeks. […] So it was that, in turn, I, my colleague, Prof Cardani, rector of the University of Parma and lieutenant of the Genio […] and some other officers, decided to try the method. That Captain, who came from France, knew nothing about the experimental arrangements used by the French [...].
> With a few devices from my laboratory and from the laboratory of physiology of Senator [Giulio] Fano, we immediately began to work. In the free hours, gun shots were fired in a corner of the courtyard, and the precise point from which they had started was sought [7, p. 406-407].

The first results, obtained using gunshots, were encouraging so much that the method was considered worthy of interest by the Ministry of War, and it was decided that it was perfected with experiments carried out in Livorno, during the combat exercises of the 32nd Artillery Regiment (blank shots), and later, at the polygon of Nettuno (near Rome), where real projectiles were fired.

At war with the hyperbolas: The "Garbasso-Cardani Method"

This method, referred to in military documents of the time as the "Garbasso-Cardani Method",[8] was based on the presence, near the enemy line, of three stations for listening the *cannon shot* and a central station (e.g. Fig. 2) that collected and processed the data. The stations were placed in convenient places, taking into account the landscape, and the need to conceal them. There was also an advanced station, the *acoustic look-out* (located about 500 m before the listening stations toward the enemy line), that received the sound of the cannon shot a few seconds before the other three and alerted them with an electric signal, produced by the *cicada* (buzzer).

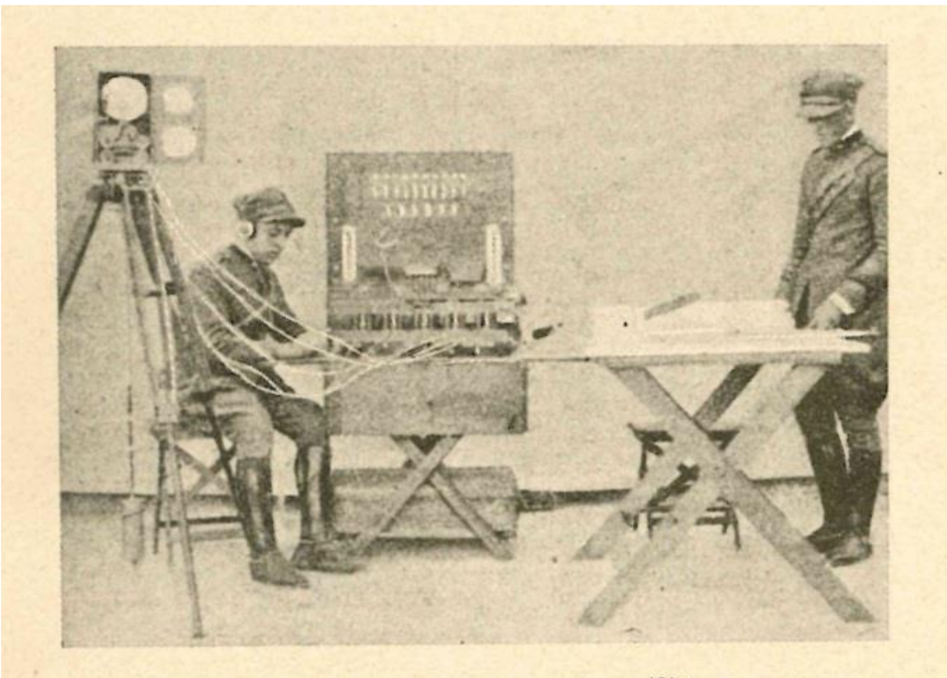

Fig. 2 – Military phonotelemetric central station [21, p. 772] Courtesy of Dr. Andrea Cattabiani, Parma.

The observers in the three stations, the "signallers", signalled to the central station the instant they perceived the blow with an electric device (e.g. by closing a circuit by means of a Morse key). These signals were recorded by the central station with a chronograph, which, in addition to recording the times, measured the intervals between the recordings of the different stations. The chronograph was combined with a double mass pendulum which regulated its movement.

On the basis of these data, that is the differences in the observation times in the three stations, and using a geometrical method based on the "hyperbolas", Garbasso and Cardani could locate the enemy artillery without visual cues.

Here is the analytic procedure for identifying the location. Consider firstly the two stations S1 and S2 (Fig. 3). Let us assume that they hear the shot at times t1 and t2, respectively, with $t1<t2$. Surely the enemy cannon is nearer to S1 than S2. Suppose that the cannon has fired at the (unknown) time t0. By taking into account the speed of sound v, which does depend on the air temperature and pressure in a well known way, we can say that the enemy cannon is at a distance d1=v(t1-t0) from S1, and d2=v(t2-t0) from S2. Of course, d1 and d2 are not known yet, but their difference d2-d1=v(t2-t1) is known, from the recording at the central station. Therefore, the location of the cannon will be in some position on the locus of the points which have a definite value d2-d1 for the distances from the two stations. This locus is a branch A of some hyperbola with foci at S1 and S2. The branch is that nearer to S1, because this station was the first to perceive the shot. By proceeding in the same way with respect to the stations S2 and S3, we can define a second branch B of hyperbola, as shown in Fig.3, where we have assumed that $t2<t3$. Surely the two curves meet, because the data correspond to the real case of the cannon shot. It could happen that they meet at two points. Then the location P of the enemy cannon will be of course at the intersection point in the enemy territory. At this point, as reported by Garbasso, we are able to establish the position of P: "since P will have to stand both on one hyperbola and on the other, it will be in one of their points of intersection" (the one closest to the enemy front). With three stations and three observers, "it is therefore possible to locate a piece [of artillery] even without seeing the blaze" [7, p. 416].

At the central station (Fig. 2), it was necessary to draw hyperbolas on the basis of the received data. The documents do not say how this was achieved, because clearly the issue should be considered as a military secret. In fact, it was necessary to combine two conflicting exigencies: a good precision in the determination of the position P and a fast procedure. In this way it was possible to "flood" the area near P by hundreds of shells fired by howitzers, so to destroy the enemy cannon and its servants, before it was moved to a different position. At the times, some mechanical devices were available, in order to draw on the map hyperbolas of given foci and distance difference [see for example 9]. An alternative way was to proceed by successive approximations, by drawing circles with increasing radius r, with center in S1, and radius r+d2-d1, with center in S2, so to obtain points on A through their intersections.

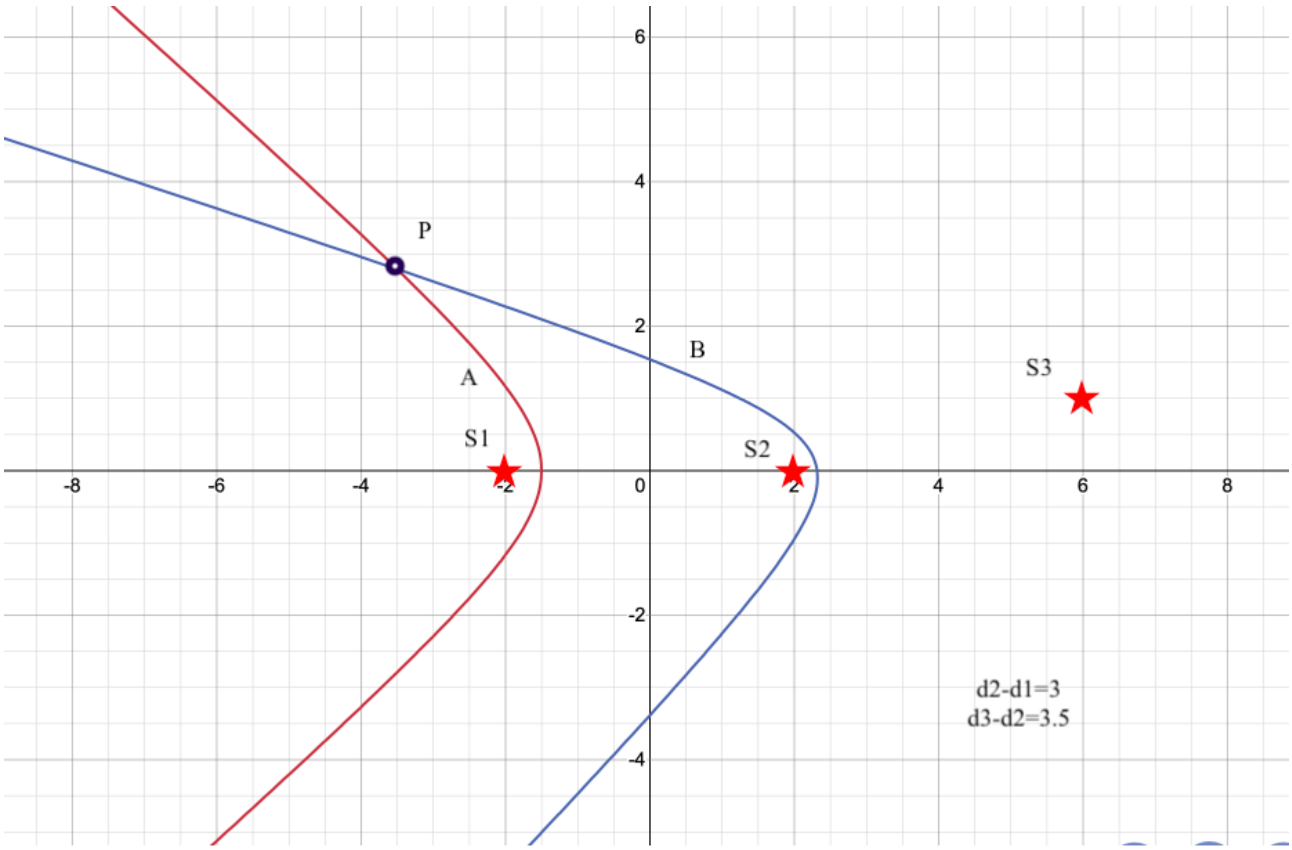

Fig. 3 – Diagram showing the observation posts (S1, S2 and S3), the left branches of two hyperbolas (A, B) and their point of intersection, P, where the enemy station is located. Distances on the map are in arbitrary units.

The method works!

This method, once developed, had to be tested and calibrated on the site for which it was conceived: the front. Garbasso and Cardani reached the front in the autumn of 1915, after many hazards (“a fortnight ago – Garbasso wrote to Volterra on December 26, 1915 – I had the pleasure of getting five shots fired at me, fortunately too high”). On December 27, 1915, they moved to San Canziano (on the Isonzo front near Monfalcone), by order of the Supreme Command, to install a complete plant for the acoustical detection of the enemy batteries [10].

Only a month later, on January 27, 1916, the plant gave a first demonstration of its efficacy. As reported by Garbasso, “an enemy battery was immediately ‘counterattacked’ with some 149 howitzers [e.g. see Fig. 4] and was then silent” [7, p. 419]. After this first success, the San Canziano central station was soon visited by SAR The Duke of Aosta (who was also commander of the Italian Third Army during the war) and, later, by SM the King of Italy (as well as by various Italian physicists, including Volterra).

Fig. 4 – Antonio Garbasso on the front (standing on the left with a cane) in front of one of the howitzers which served with Italy during the Great War (Fondo Garbasso, Osservatorio Astrofisico di Arcetri).

The phonotelemetric service was gradually extended to the whole front, first on the Isonzo and then on the Piave. Garbasso will remain on the trenches for the entire duration of the conflct. On August 2, 1916, two days before the beginning of the Battle of Gorizia, the most successful Italian offensive along the Isonzo river, Garbasso wrote to Volterra as follows:

> I keep organizing the [phonotelemetric] service, which is gradually extending. And I am also making a career, so much that I have been promoted to Captain! Perhaps we are close to reaping the fruits of a long patient work; but for now, this should not be discussed [11].

In October 1916 the phonotelemetry service was assigned to the Artillery and Garbasso became its Director. The headquarters of the Direction was in Manzinello (Municipality of Manzano), under the direct dependence of the Italian Supreme Military Command of the Royal Army, which until Caporetto was located in Udine at the Regio Liceo Classico Jacopo Stellini (the local classical lyceum) [12][13]. However, there were not a few difficulties coming from the Military Command that Garbasso had to overcome. As Garbasso wrote to Volterra on December 20, 1916:

> The work proceeds, although there is always the passive resistance (sometimes active) of many leaders, who have a quite peculiar concept of science and its applications. A lieutenant general told me the other yesterday, with the air of one who utters a profound truth, that "war is not done with hyperbolas" [14].

Subsequently, the phonotelemetric service passed to the “Ufficio Invenzioni” (Office of Inventions) at the Undersecretariat for Arms and Ammunition of the Italian Ministry of War, which was founded on March 17, 1917 and of which Volterra took over its management. This office was organized by Volterra following the example of similar institutions set up abroad, in particular the French office “Direction des Inventions Interéssant la Défense Nationale” (DIIDN), and was founded as a “technical advisory body for the various Ministries” [15].

In the meantime the phonotelemetric method was perfected as far as its application in the mountains was concerned, where it was necessary to take into account the various differences in level of the terrain (Fig. 5). This task was carried out in an excellent way by Francesco Severi (at that time lieutenant of artillery), who went on to become the leading mathematician of the Roman school of Algebraic Geometry.

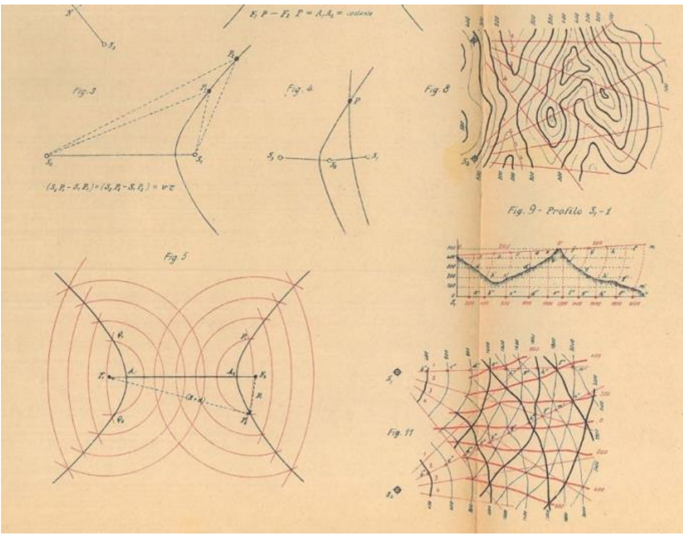

Fig. 5 – Diagrams about phonotelemetry on non-level terrain. Details of table n. 1 in [22]. Courtesy of Dr. Andrea Cattabiani, Parma.

Before the defeat of Caporetto (October 24, 1917) on the Isonzo front, when the Italian Second Army collapsed under the attack of Austro-Hungarians and Germans, 10 phonotelemetric sections were installed (3 in Trentino and 7 on the Isonzo front) and had some good results. When the Italian front moved back to the Piave river, as the flat terrain and the thick vegetation made it very difficult to identify the enemy positions by observers on the ground or by tethered balloons, this method became indispensable and was strongly strengthened.

The Garbasso-Cardani method, however, was only one of the many acoustic methods to detect the enemy positions developed during the war by the allies. One notable example is the sound-ranging method developed by William Lawrence Bragg, 1915 Nobel Prize in Physics (jointly awarded to him and to his father, William Henry, “for their services in the analysis of crystal structure by means of X-rays”). His method, which allowed to pinpoint the position of enemy artillery pieces by recording the boom of their firing with an array of microphones, proved to be valuable in the British victory at the battle of Cambrai (November – December 1917) and vital for that at Amiens (August 1918) [16].

Another method was that developed by the French in the early months of 1915, initially based on hand signals. Subsequently, they introduced systems with automatic receivers, including the so-called Cotton-Weiss system [17][18].

After the founding of the Office of Inventions, Volterra, in collaboration with the similar French, British and American Allied Offices and with the contribution of Garbasso, managed to compare the Italian system with the "foreign" ones and to evaluate if it was advisable to introduce in Italy one of the foreign systems. Although the tests performed gave unsatisfactory results, it was decided "the purchase of a Cotton-Weiss system phonotelemetric station". This one, however, proved difficult to use, especially in the mountain areas [19].

In the meantime, the strengthening of the Garbasso-Cardani network continued unabated. In the spring of 1918 the sections on the front equipped with the system "Garbasso-Cardani" amounted to 18 and included 108 stations, 70 officers and a thousand men. Garbasso will write with great pride: "From [Mount] Grappa [the most important pillar of the Italian defence] to the sea there was no solution of continuity along our lines" [7, p. 429].

The sound ranging network built by Garbasso, which adopted the all-Italian system that had proved to be the most appropriate one for the Italian landscape, contributed to the success of the Italian 3rd and 4th Armies and of the Allied troops on the Piave front in the final part of the war. Not surprisingly, Garbasso was decorated with the *Croce di Guerra* (Cross of War) [7, p. 405].

The phonotelemetry on display: a good example of interdisciplinarity

An exhibition on the phonotelemetry was held in early 2016 Parma, i.e. the town whose University had as its Rector just Pietro Cardani, one of the two scientists responsible for the phonotelemetric method. The exhibition was designed with the grade-12 students of a class of a Parma's upper secondary school (Liceo Sanvitale) and was located in the same school. It consisted in a number of posters, devoted to the historical background of the Great War and to the physics of phonotelemetric method [20].

The exhibition included also interactive experiments on the characteristics of sound and a battlefield model (Fig. 6) with the goal of reconstructing, in hands-on mode, the working of this sound ranging technique and understanding its versatility.

The exhibition lasted two months and was seen by more than 1,000 visitors (over 800 primary and secondary school students and a general audience of over 200). Given that Parma is a rather small town (less than 200,000 inhabitants), 1000 visitors are not so few.

The educational value of the exhibition was on three axes: *culture*, i.e. enabling the students who co-designed the exhibition to place a specific piece of sound physics within its historical context; *motivation*, that is inspiring students to study physics by connecting the discipline with a real-life problem actually faced by scientists in the past; and, finally, *knowledge acquisition*, namey helping students to understand sound physics out of a problem-solving task

The cultural and motivational roles were explored through the qualitative analysis of essays written by the students at the end of the exhibition with the goal of explaining their personal impressions and elaborating on strong and weak points of the experience. Almost the whole sample emphasized the educational benefits of their studying and learning a historical-scientific topic in such a way to be able to interest their peers and the general audience. Its benefits on the knowledge acquisition were studied by administering open-ended and closed questions on wave propagation right after the exhibition and again at the end of the scholastic year. The analysis of these items suggest that the experience promoted a meaningful and lasting learning.

Fig. 6 – The battlefield created by the students for the simulation of the phonotelemetric method.

Conclusions

This is not the place to discuss whether the Great War was futile and the (many) deaths meaningless, or whether it was a just answer to the aggression of the Central Powers. Rather, this is the place of a much more focused – educational – look, a look aimed at the mobilization of a number of (Italian) scientists after the onset of the state of war.

In this regard, the case-study on phonotelemetry was a starting point for an educational activity on the physics of sound, but it was not limited to this. It was also, as we have seen above, an opportunity for interdisciplinary work between mathematics, physics and history, with the triple objective of enabling the students to place a specific piece of physics within its historical context, inspiring students to study physics by connecting the subjects with a real-life and helping students to understand physics out of a problem-solving task.

The transposition of this case-study to the field of physics education had also another important aspect, concerning the nature of science, and more specifically, the public – civil and military as in this case – commitment of scientists. This commitment is evident in the motivations of the assignment of the Cross of War to Garbasso:

> He introduced the phonotelemetric system in war applications, organized the service, and tested and directed it on the middle and lower Isonzo [front], in the most advanced stations and in areas under enemy fire. This arduous work he performed in silence, for more than two years, animated by a lively faith in the future and in the effectiveness of the phonotelemetric system for the search of the enemy artillery. And, in fact, phonotelemetry is now one of the most valid means […] to establish the location of enemy artillery. During the [Caporetto] retreat it took care, through appropriate provisions, of the safeguard of all the material of all the sections. This material immediately served, on the Piave [front], to the 3rd and 4th Armies and to the Allied troops. On this occasion, Captain Garbasso always checked in person the systems and the working of the very advanced stations of the

> Montello [hill], Maserada [sul Piave] and Sile [river] [war theaters of the Second Battle of the Piave river, a decisive victory of the Italian Army] [7, p. 405].

The awarding of the Cross of War to Garbasso was a recognition not only to the scientific contribution given by him to the Great War, but above all to his public commitment. Examples like this, in which a scientist manages to reconcile his scientific skills with his social and political aspirations are not so infrequent in the history of science and must be studied and disseminated, especially among the younger generations, as symbols to regain and render palpable what happened a hundred years go. And this is the most important message of this article.

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