

The power of education: reflections from a Nobel laureate - Part II Waves: the invisible dance that shapes our world

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Introduction

On April 17, 2024, I had the privilege of attending another enlightening presentation by Anne L'Huillier, the 2023 Nobel laureate in Physics, at Vetenskapsfestiven in Gothenburg. Vetenskapsfestiven translates to "Science Festival" in English. The theme of the presentation was "waves", a concept that is fundamental to our understanding of the universe, yet often goes unnoticed in our daily lives.

In this second lecture, L'Huillier delved deeper into the world of waves, exploring their profound impact on our understanding of the universe and our technological advancements. She emphasized the omnipresence of waves, from carrying our voices in a conversation, bringing music to our ears, and colours to our eyes, to traveling through space, bringing information from the farthest stars. The lecture began with an exploration of sound waves, the vibrations that allow us to communicate and appreciate music. We were then taken on a journey through the electromagnetic spectrum, where light waves enable us to see the world around us. But waves are not limited to sound and light. They are also fundamental to our understanding of quantum physics. Subatomic particles, like electrons, are not just particles, but also waves. This wave-particle duality is one of the pillars of quantum mechanics and was one of the most fascinating topics of the presentation.

The lecture also highlighted how waves are used in modern technology. From radio waves enabling wireless communication, to ultrasound waves used in medicine, waves play a crucial role in many aspects of our lives. If you've read the previous article,¹ you know that children, with their imaginative ideas about the flight of eggs, embody the essence of learning. They remind us that education goes beyond textbooks and classrooms; it's about nurturing young minds to explore, question, and dream. These discoveries exemplify how science can shed light on life's mysteries and foster curiosity and innovation in today's minds. Each of these revelations opens new doors to understanding the complexity of life at both macroscopic and microscopic levels, challenging the gravity of established knowledge, igniting curiosity, and shaping a brighter future. In today's interconnected world, waves serve as a fundamental concept

spanning across disciplines—from the gentle ripples in a pond to the electromagnetic waves that enable modern communication. Understanding waves not only enhances our comprehension of natural phenomena but also drives technological advancements that shape our daily lives. Whether exploring the behavior of sound waves in music and acoustics or harnessing the power of ocean waves for renewable energy, the study of waves inspires creativity and problem-solving.

At the heart of scientific exploration lies education. By integrating hands-on experiences and inquiry-based learning into curricula, educators can empower students to grasp the intricate dynamics of waves and their applications. Engaging young minds in wave-related experiments and projects not only cultivates critical thinking and analytical skills but also instils a passion for discovery that extends beyond the classroom. Moreover, the fascination with waves extends into the realms of space exploration, where gravitational waves offer unprecedented insights into cosmic phenomena, confirming Einstein's theories and unveiling new frontiers in astrophysics.² Meanwhile, in biomedical fields, ultrasound waves revolutionize diagnostics and therapeutic treatments, illustrating how waves bridge scientific theory with practical applications in healthcare.

As we celebrate the interconnectedness of science and education at events like Vetenskapsfestiven in Gothenburg, we honor pioneers like Anne L'Huillier, whose groundbreaking research in physics continues to inspire and shape our understanding of waves.^{3,4} By fostering a collaborative environment that encourages dialogue between scientists, educators, and young learners, we pave the way for future discoveries that will redefine our world.

Gravitational waves: revealing the hidden universe

Gravitational waves, predicted by Einstein and detected for the first time in 2015, are ripples in the fabric of space time caused by cataclysmic cosmic events such as the collision of black holes. These waves represent a revolutionary tool for observing the universe, offering a new window into phenomena that were previously invisible to traditional astronomical methods.² The discovery of gravitational waves marks a significant milestone in our quest to understand the

cosmos. Albert Einstein's general theory of relativity, published over a century ago, predicted the existence of these waves as disturbances in space time generated by massive accelerating objects. However, it wasn't until the Advanced LIGO (Laser Interferometer Gravitational-Wave Observatory) detectors came online that scientists were able to directly observe these elusive waves.^{2,5}

Electromagnetic waves: the foundation of modern technology

From the visible light that illuminates our world to the microwaves essential for communication, electromagnetic waves play a pivotal role in our understanding of the universe and the advancement of technology. The unification of electricity and magnetism was achieved through Maxwell's equations, a set of four differential equations that describe how electric and magnetic fields interact. These equations, formulated by James Clerk Maxwell, laid the groundwork for the field of electromagnetism and paved the way for numerous technological innovations. One such innovation was the discovery of radio waves by Heinrich Hertz. Hertz's ground breaking experiments in the late 19th century demonstrated the existence of electromagnetic waves, confirming Maxwell's theoretical predictions. His work marked the dawn of the wireless communication era, revolutionizing the way we transmit information and interact with the world around us. In his paper, "Heinrich Hertz and the Development of Physics," author provides an in-depth look at Hertz's contributions to physics and their lasting impact on the field. Hertz's pioneering research not only validated Maxwell's equations but also set the stage for the development of radio, television, radar, and numerous other technologies that we rely on today. As we continue to explore the potential of electromagnetic waves, from harnessing solar energy to developing quantum communication systems, it's clear that the legacy of Maxwell and Hertz lives on, driving the progress of modern technology. In September 2015, the first detection of gravitational waves, known as GW150914, confirmed Einstein's theory and opened a new era of gravitational wave astronomy. This landmark event was followed by subsequent detections, each unveiling new insights into the dynamics of the universe. For instance, the merging of two black holes, detected through these waves, not only validated our theoretical understanding but also provided clues about the formation and evolution of galaxies.⁵

The impact of gravitational wave astronomy extends beyond theoretical physics. It enables scientists to probe the most violent and energetic events in the universe, such as neutron star mergers and supernovae explosions, with unprecedented precision. By analysing the gravitational wave signals, researchers can extract detailed information about the properties of celestial objects and the fundamental laws of gravity under extreme conditions.^{2,5} Moreover, gravitational waves offer a complementary perspective to electromagnetic astronomy. Unlike light, which can be obstructed by cosmic dust and gas, gravitational waves pass through the universe unhindered, offering a clear view of events that would otherwise remain hidden. This capability promises to revolutionize our understanding of black holes, neutron stars, and other enigmatic cosmic phenomena. The future of gravitational wave research is promising. Advanced detectors like LIGO and Virgo continue to improve in sensitivity, enhancing our ability to detect increasingly faint signals from distant sources. Furthermore, upcoming projects such as the Laser Interferometer Space Antenna (LISA), a space-based observatory planned for launch in the 2030s, will extend our observational reach to lower frequencies, opening new frontiers in astrophysics.⁵ In conclusion, gravitational waves represent not only a triumph of theoretical physics

but also a transformative tool for exploring the hidden corners of the universe. They promise to unravel longstanding mysteries, deepen our understanding of cosmic evolution, and inspire future generations of scientists to push the boundaries of human knowledge.

Sound waves: exploring the world through sound

Sound waves are fundamental to communication and music. They are mechanical waves that propagate through mediums such as air and water. The study of sound waves, known as acoustics, has applications in various fields, from audio engineering to medicine, with the use of ultrasound for diagnosis. Sound waves are produced by the vibration of an object, which creates a disturbance in the surrounding medium. This disturbance travels through the medium as a wave, carrying energy from one place to another. The human ear is capable of detecting these waves, which we perceive as sound. Kinsler and his co-authors provide a comprehensive introduction to the principles and applications of acoustics. They delve into the physics of sound, exploring topics such as wave propagation, resonance, and sound perception.⁶

In the field of medicine, sound waves are used in the form of ultrasound. Ultrasound imaging is a non-invasive diagnostic technique that uses high-frequency sound waves to create images of the inside of the body. Cootney discusses the use of ultrasound imaging in biomedical research, highlighting its potential for advancing our understanding of disease processes.⁷ As we continue to explore the potential of sound waves, from enhancing audio technology to improving medical diagnostics, it's clear that the study of acoustics will continue to play a vital role in the advancement of science and technology.

Surface waves: the motion of the oceans

Surface waves in the oceans, caused by wind and other forces, are a visible example of mechanical waves. They not only influence navigation and weather, but are also a source of renewable energy through wave energy technology. Surface waves are generated when wind interacts with the surface of the sea. The energy transferred from the wind to the water creates waves that travel across the ocean surface. These waves can travel vast distances, carrying energy from their point of origin to distant shores. Falnes and Løvseth provide an in-depth look at the potential of harnessing the power of ocean waves for energy production. They discuss the principles of wave energy conversion and explore various technologies designed to capture and convert this energy into usable electricity.⁸ Wave energy technology offers a promising solution to the world's growing energy needs. By harnessing the power of the ocean, we can generate clean, renewable energy, reducing our reliance on fossil fuels and mitigating the impacts of climate change. As we continue to explore the potential of surface waves, from improving our understanding of ocean dynamics to advancing wave energy technology, it's clear that these waves will continue to play a vital role in our world.

Shock waves: powerful forces in action

Shock waves, generated by explosions or objects moving at supersonic speeds, carry a tremendous amount of energy and can cause significant damage. However, they also have beneficial applications, such as in medicine for breaking kidney stones using lithotripsy. Shock waves are characterized by a sudden change in pressure, temperature, and density. They are typically generated by events that release a large amount of energy in a small area, such

as an explosion or a supersonic aircraft breaking the sound barrier. The energy from these events propagates outward as a shock wave, carrying a significant amount of force. In the medical field, shock waves are used in a procedure known as extracorporeal shock wave lithotripsy (ESWL). This non-invasive treatment uses shock waves to break kidney stones into small pieces that can then be passed naturally through the urinary tract. Carmignano discusses the use of shock wave therapy for treating chronic wounds. This therapy promotes wound healing by stimulating cell proliferation and enhancing blood circulation. Similarly, Vandeursen and Baert discuss the use of ESWL (Extracorporeal Shock Wave Lithotripsy) for treating kidney stones. They highlight the effectiveness of this treatment, particularly with the use of second-generation lithotripters. As we continue to explore the potential of shock waves, from understanding their destructive power to harnessing their therapeutic benefits, it's clear that these powerful forces will continue to shape our world.

Waves and molecular biology

The connection between waves and molecular biology can be seen in how wave-based techniques are used to study biological processes. For example, Nuclear Magnetic Resonance (NMR), which is based on radio waves, allows for the detailed visualization of molecular structures. Similarly, ultrasounds are used to investigate biological tissues without causing harm.⁹ Nuclear Magnetic Resonance (NMR) is a powerful tool in molecular biology. It uses the magnetic properties of certain atomic nuclei to provide detailed information about the structure, dynamics, reaction state, and chemical environment of molecules. This technique has been instrumental in studying a wide range of biological systems, from small biomolecules like proteins and nucleic acids to large complex systems like viruses.⁹ Ziarek and his co-authors discuss the latest advancements in NMR-based molecular biology. They highlight the potential of NMR in providing insights into the complex world of molecular biology.⁹ Ultrasound, on the other hand, is a non-invasive technique that uses high-frequency sound waves to create images of the inside of the body. It is commonly used in medicine for diagnostic purposes, but it also has applications in molecular biology. For instance, it can be used to study the mechanical properties of biological tissues, which can provide valuable information about their health and function.¹⁰

As scientists continue to explore the potential of wave-based techniques in molecular biology, it's clear that these methods will continue to play a crucial role in advancing our understanding of life at the molecular level.

The future of waves in science and education

The study of waves is not just a fascinating area of physics, but also a bridge to other disciplines, such as molecular biology and medicine. Through education, we can inspire future generations to explore these complex phenomena, stimulating innovation and scientific progress. Waves, in their various forms, are fundamental to our understanding of the universe. From the electromagnetic waves that light up our world to the sound waves that enable communication, waves are integral to our daily lives. In the field of science, the study of waves has led to breakthroughs in areas as diverse as quantum mechanics, telecommunications, and medical imaging. Education plays a crucial role in fostering an understanding and appreciation of waves. By incorporating the study of waves into the curriculum, educators can ignite students' curiosity and inspire them to pursue careers in science and technology. Innovative teaching methods, such

as the use of interactive simulations and hands-on experiments, can make the study of waves more engaging and accessible to students.

Blackie discusses the use of Legitimation Code Theory (LCT) in chemistry education. LCT is a framework that can help educators design lessons that build on students' existing knowledge and skills, facilitating a deeper understanding of complex scientific concepts.¹¹ As we look to the future, the study of waves will continue to be a vital area of scientific research and education. By fostering a culture of curiosity and innovation, we can inspire the next generation of scientists and engineers to push the boundaries of our understanding and harness the power of waves to solve some of the world's most pressing challenges. The Importance of Waves in Education in Brazil, where I come from, I wish we could embrace this perspective more fully. Imagine if every child had the opportunity to engage in stimulating competitions or participate in hands-on experiments. How could this shape our society? How many brilliant minds could emerge? Education is not just about preparing students for exams; it's about preparing them for life, instilling critical thinking skills, empathy, and a passion for discovery. By celebrating the innovative work of scientists who study waves in their various forms, we recognize that education plays a fundamental role. Imagine a world where every child has the opportunity to engage in stimulating competitions or participate in hands-on experiments. This could significantly shape our society, potentially giving rise to numerous brilliant minds. Education is not just about preparing students for exams; it's about preparing them for life, instilling critical thinking skills, empathy, and a passion for discovery.

By celebrating the innovative work of scientists studying waves in their various forms, we acknowledge the crucial role that education plays. The study of waves, whether they be sound waves, light waves, or even seismic waves, offers a wealth of opportunities for practical learning and application. These scientific concepts can be brought to life in the classroom, sparking curiosity and fostering a deeper understanding of the world around us. This not only equips students with valuable knowledge but also encourages them to think creatively and problem-solve, skills that are essential in today's rapidly evolving world. In embracing this approach more fully, we can inspire future generations to explore these complex phenomena, driving innovation and scientific progress. This could lead to breakthroughs in various fields, from technology to medicine, ultimately benefiting society as a whole. In summary, the presentation at Vetenskapsfestiven was a captivating journey through the world of waves. It underscored the importance of waves in our understanding of the universe and in our technology. And perhaps most importantly, it reminded us that even if we cannot see waves, they are always there, shaping our world in ways we often do not realize.¹²

As I reflect on these two lectures, I am struck by the power of education and the importance of scientific exploration. The work of researchers like Anne L'Huillier not only advances our understanding of the universe but also inspires the next generation of scientists. I look forward to attending more such enlightening presentations in the future. In conclusion, the exploration of waves not only enriches our scientific knowledge but also nurtures a generation of thinkers who are poised to tackle global challenges with ingenuity and empathy. As we embark on this journey of discovery, let us embrace the waves of knowledge that propel us towards a more enlightened and interconnected future. So, let's advocate for education - whether through formal institutions or informal exploration - because it holds

the key to progress. Let's inspire young minds to explore how waves, challenging the status quo, igniting their curiosity, and shaping a brighter future.

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Conflicts of interest

The author declare that there are no conflicts of interest.

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