

THE IMPORTANCE OF INDEPENDENT LEARNING IN IMPROVING THE QUALITY OF MEDICAL EDUCATION

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Abstract

This article examines the importance of independent learning in improving the quality of medical education, using the topic “Physical Foundations of the Auditory System” taught in medical and biological physics as an example.

Keywords

Independent learning, sound, auditory system, outer ear, middle ear, inner ear, ear diagram, hearing physiology, quality of education.

Relevance. It is well known that improving the quality of education is a matter of national importance and an urgent issue that must be addressed in order to train competitive national specialists. Therefore, on the initiative of our President, numerous documents aimed at improving educational quality have been developed and implemented in practice.

For example, at the extended meeting of the Cabinet of Ministers held on January 14, 2017, the Head of State emphasized the necessity of fundamentally revising curricula and educational programs within the education system. It was noted that alongside qualified personnel, regulatory documents and educational-methodological support play a significant role in organizing effective lessons in educational institutions.

Similarly, the Decree of the President of the Republic of Uzbekistan “On the Concept for the Development of the Higher Education System of the Republic of Uzbekistan until 2030” also addresses issues related to educational quality.

The Law of the Republic of Uzbekistan “On Education” (No. ORQ-637, September 23, 2020) covers reforms in the education system, the development of vocational education (schools, colleges, technical schools), the establishment of a two-stage higher education system (bachelor’s and master’s degrees), as well as the rights and responsibilities of learners, the status of teachers, and the licensing of non-state educational institutions. One of the key changes is the expansion of

pathways for vocational and higher education after nine years of basic secondary education, as well as the opportunity to obtain a second professional education on a contractual basis.

Other official documents also continuously address the issue of improving educational quality.

In this article, we examine the importance of independent learning in improving educational quality through the example of the topic “Physical Foundations of the Auditory System.” In studying this topic, we apply the method of using literature resources within independent learning.

Key Aspects:

- **Forms of education:** General secondary education; specialized secondary education (nine years + two years); initial vocational education (nine years + two years); and higher education.

- **Vocational education:** Implemented through vocational schools, colleges, and technical schools, with the possibility of obtaining a second education on a contractual basis.

- **Higher education:** Consists of Bachelor’s degree programs (basic higher education) and Master’s degree programs (specialized education).

- **Rights:** Citizens are guaranteed the right to receive education at various levels.

- **Purpose of the Law:** To improve the education system, train highly qualified personnel, and protect the rights of learners and educators.

The Law is aimed at modernizing the education system and creating new educational directions, and it plays a particularly important role in developing vocational education and expanding opportunities for obtaining higher education. In this article, we examine the importance of independent learning in improving the quality of education using the topic “*The Physical Foundations of the Auditory System*” as an example. First, we consider the concept of independent learning and its various types. The auditory system consists of complex physical and biological processes. The frequency, intensity, and pressure of sound, as well as the anatomical structure of the ear, play a crucial role in its perception.

Outer		Ear
Function:	Collection of sound	waves.
Structure:	The auricle collects sound waves and directs them through the external auditory canal. The outer ear consists of the auricle (pinna), cartilage covered with skin, and the external auditory canal—an irregularly shaped cylindrical passage approximately 25 mm in length, lined with ceruminous (wax-secreting) glands.	

2.

Middle

Ear

Function: Amplification of sound vibrations.

Structures:

Tympanic membrane: Vibrates in response to incoming sound waves.

Ossicles: The small bones – malleus, incus, and stapes – amplify the vibrations of the tympanic membrane and transmit them to the oval window in accordance with the laws of mechanics.

The middle ear consists of the tympanic cavity, an air-filled space whose lateral wall is formed by the tympanic membrane (eardrum). It communicates with the nasopharynx via the Eustachian tube, which maintains pressure equilibrium on both sides of the tympanic membrane. For example, this connection allows pressure equalization during swallowing and helps restore hearing acuity lost due to rapid changes in barometric pressure (e.g., during aircraft landing or rapid elevator movement). The tympanic cavity also contains the auditory ossicles – malleus, incus, and stapes – controlled by the stapedius and tensor tympani muscles. The tympanic membrane is connected to the inner ear through the ossicles, particularly via the mobile footplate of the stapes, which is positioned against the oval window.

3.

Inner

Ear

Function: Conversion of mechanical vibrations into neural signals.

Structures:

Cochlea: A spiral-shaped organ containing perilymph and endolymph (fluids).

Organ of Corti: Located within the cochlea. Vibrations transmitted from the stapes set the cochlear fluids (perilymph and endolymph) into motion, which in turn stimulate the hair cells of the Organ of Corti.

Neural impulses: The movement of hair cells is transformed into electrical signals and transmitted to the brain via the auditory nerve (electrochemistry and neurophysiology). The inner ear contains the sensory apparatus itself. It consists of a bony shell (the bony labyrinth), within which lies the membranous labyrinth – a closed system of interconnected cavities filled with endolymph, a potassium-rich fluid. The membranous labyrinth is separated from the bony labyrinth by perilymph, a sodium-rich fluid. The bony labyrinth comprises two main parts. The anterior portion, called the cochlea, is the true organ of hearing; it has a spiral configuration resembling a snail shell and is oriented anteriorly. The posterior portion includes the vestibule and the semicircular canals, which are responsible for balance.

The neurosensory structures involved in hearing and equilibrium are located within the membranous labyrinth: the Organ of Corti lies in the cochlear duct,

whereas the maculae of the utricle and saccule and the ampullae of the semicircular canals are situated in the posterior part.

Physical Principles:

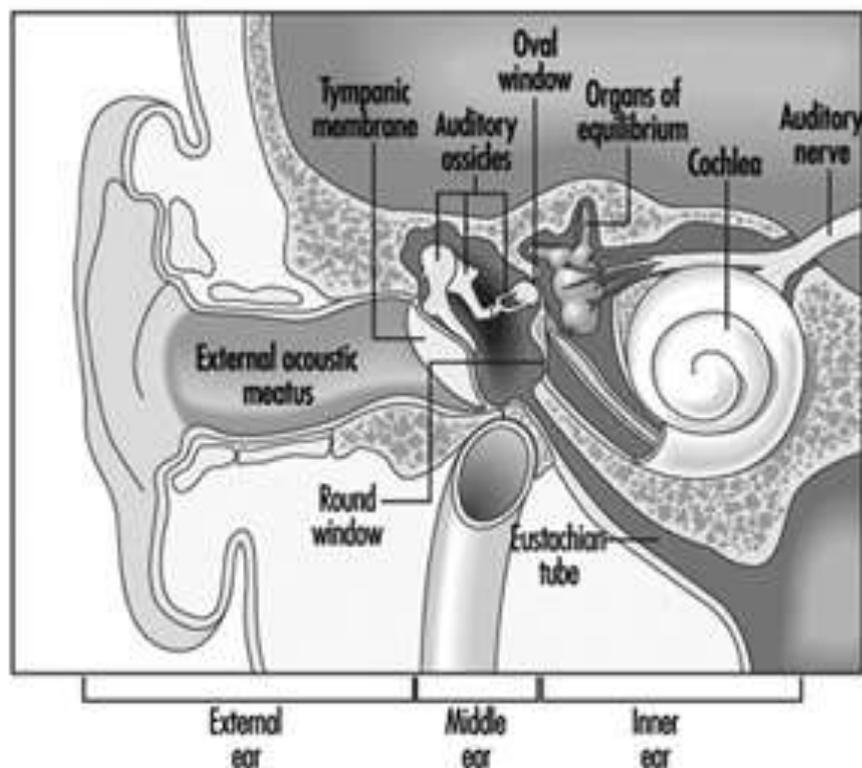
- **Sound waves:** Variations in air pressure that propagate as mechanical waves.
- **Resonance:** The fluids and hair cells within the cochlea respond to sound vibrations of different frequencies through resonance.

Amplification effect: The ossicles of the middle ear amplify sound energy by transmitting it from a larger surface area (the tympanic membrane) to a smaller surface area (the oval window), in accordance with the laws of physics.

It is well known that studying the physical foundations of the auditory system is of great importance for medicine, biology, and engineering sciences. With the increasing level of environmental noise and the rapid development of technology and industry, the incidence of hearing-related disorders—particularly hearing loss and deafness—is steadily rising. Therefore, a deep understanding of the physical properties of sound and the mechanisms of its perception by the ear is essential.

Knowledge of the physical bases of the auditory organs plays a crucial role in the early detection of hearing impairments and in establishing accurate diagnoses. Modern diagnostic methods such as audiometry, impedancemetry, and otoacoustic emission testing are fundamentally based on the laws of acoustics and vibration physics. Studying this topic helps future medical professionals understand the operating principles of diagnostic equipment. Moreover, the development and improvement of medical-technical devices such as hearing aids and cochlear implants also require knowledge of the physical principles of hearing. Correct modeling of the processes of sound amplification, filtering, and conversion into neural impulses contributes to improving patients' quality of life. This topic is also highly relevant in occupational hygiene and environmental health. Assessing the impact of industrial noise on the human auditory system, establishing permissible noise limits, and developing preventive measures are all based on physical principles. The ear is a sensory organ responsible for hearing and balance, determining body position and head movement. It consists of three parts: the outer, middle, and inner ear. The outer ear lies outside the skull, whereas the other two parts are embedded within the temporal bone (Fig. 1).

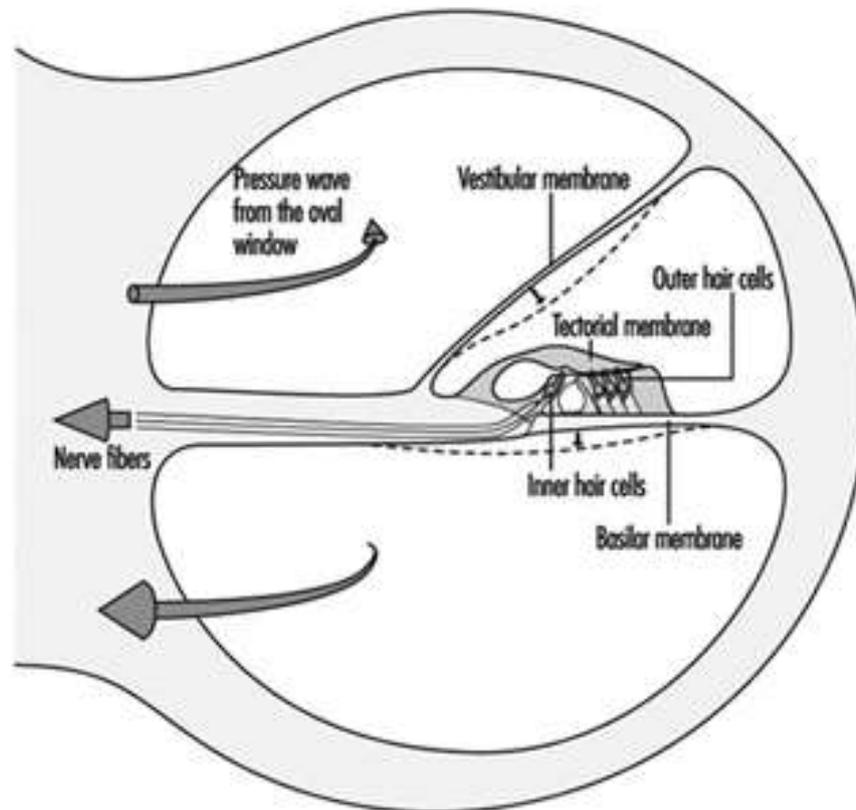
Figure 1. Diagram of the Ear.



Source: Hahmann and Schmuckl 1989.

Auditory Organs

The cochlear duct is a spiral-shaped, triangular tube consisting of approximately two and a half turns, separating the scala vestibuli from the scala tympani. One end terminates at the spiral ligament, forming the central pillar of the cochlea, while the other end is connected to the bony wall of the cochlea. The scala vestibuli and scala tympani terminate respectively at the oval window (footplate of the stapes) and the round window. The two chambers communicate at the apex of the cochlea via the helicotrema. The basilar membrane forms the floor of the cochlear duct and supports the Organ of Corti, which is responsible for transmitting acoustic stimuli. All auditory information is conveyed by only 15,000–3,500 hair cells of the Organ of Corti, of which approximately 90 inner hair cells are critically important because they form synapses with about 30,000 primary auditory neurons (Fig. 2). Inner and outer hair cells are separated by multiple layers of supporting cells. The stereocilia of the hair cells project through an unusually thin membrane and are embedded into the tectorial membrane, whose free edge lies over the hair cells. The upper surface of the cochlear duct is formed by Reissner's membrane.



Source: Hohmann and Schmuckli 1989.

Balance Organs

Sensory cells are located in the ampullae of the semicircular canals and in the maculae of the utricle and saccule. They are stimulated by pressure transmitted through the endolymph as a result of head or body movements. These cells are connected to bipolar neurons, whose peripheral processes form two pathways: one from the anterior and lateral semicircular canals, and the other from the posterior semicircular canal.

These two pathways enter the inner ear canal and merge to form the vestibular nerve, which extends to the vestibular nuclei in the brainstem. Fibers from the vestibular nuclei, in turn, project to the cerebellar centers controlling eye movements and to the spinal cord.

The convergence of the vestibular and cochlear nerves forms the vestibulocochlear nerve, also known as cranial nerve VIII.

Physiology of Hearing

Air Conduction of Sound

The ear consists of a sound conductor (outer and middle ear) and a sound receiver (inner ear). Sound waves traveling through the external auditory canal strike the tympanic membrane, causing it to vibrate. These vibrations are

transmitted to the stapes via the malleus and incus. The surface area of the tympanic membrane is approximately 16 times larger than that of the stapes footplate ($55 \text{ mm}^2 / 3.5 \text{ mm}^2$), and together with the lever action of the ossicles, this results in a 22-fold increase in sound pressure. Due to the resonance frequency of the middle ear, the transmission ratio is optimal within the 1,000–2,000 Hz range. As the stapes footplate moves, waves are generated in the fluid of the vestibular canal. Because the fluid is incompressible, each inward movement of the stapes footplate produces an equivalent outward movement at the round window. At high sound levels, contraction of the stapedius muscle protects the inner ear (attenuation reflex). In addition, the middle ear muscles extend the dynamic range of hearing, improve sound localization, reduce resonance in the middle ear, and regulate air pressure in the middle ear and fluid pressure in the inner ear. The threshold of the attenuation reflex in the 250–4,000 Hz range is approximately 80 dB above the hearing threshold, and it increases by about 0.6 dB per dB increase in stimulus intensity. Its latency at the oval window is 150 ms, and in the presence of strong stimuli, it is 24–35 ms. Contraction of the middle ear muscles at frequencies below the natural resonance of the middle ear reduces sound transmission by approximately 10 dB. Due to its latency, the attenuation reflex provides sufficient protection against noise occurring at rates above 1–2 per second but is less effective against discrete impulse noises. The speed of sound wave propagation through the ear depends on the elasticity of the basilar membrane. Elasticity increases and wave velocity decreases from the base to the apex of the cochlea. The transmission of vibration energy to Reissner's membrane and the basilar membrane depends on frequency: high-frequency waves produce maximal amplitude at the base, while low-frequency waves produce maximal amplitude at the apex. Thus, the point of maximal mechanical stimulation in the cochlea depends on frequency, forming the basis for frequency discrimination. Movement of the basilar membrane generates shearing forces on the stereocilia of hair cells, initiating a series of mechanical, electrical, and biochemical processes responsible for mechano-sensory transduction and preliminary processing of acoustic signals. Shearing forces open ion channels in the hair cell membranes, altering their conductance and allowing potassium ions to enter the cells. This potassium influx leads to depolarization and the generation of action potentials. Depolarization triggers the release of neurotransmitters at synapses of the inner hair cells, eliciting neural impulses that travel via afferent fibers of the auditory nerve to higher centers in the brain. The intensity of auditory stimulation is determined by the number of action potentials per unit time and the number of activated cells, while perceived frequency depends on the specific populations of activated nerve fibers. A spatially organized mapping exists

between stimulus frequency and the activated regions of the auditory cortex. Inner hair cells act as mechanoreceptors, converting acoustic vibrations into electrical signals sent to the central nervous system. However, they are not responsible for the ear's sensitivity threshold or extraordinary frequency selectivity. Outer hair cells do not transmit auditory signals to the brain. Instead, they selectively amplify mechanical-acoustic vibrations near threshold levels by approximately 100-fold (about 40 dB), facilitating the stimulation of inner hair cells. This amplification is believed to operate through a micromechanical coupling involving the tectorial membrane. Outer hair cells can generate more energy than they receive from external stimuli and actively contract at very high frequencies, functioning as cochlear amplifiers. The interaction between outer and inner hair cells in the cochlea establishes a feedback loop that regulates hearing, particularly threshold sensitivity and frequency selectivity. Consequently, efferent cochlear fibers help reduce cochlear damage from intense acoustic stimuli. Outer hair cells can also undergo reflex contraction in response to strong stimuli. Thus, the attenuation reflex of the middle ear, mainly active at low frequencies, and the reflexive contraction in the inner ear, mainly active at high frequencies, complement each other.

Bone Conduction of Sound

Sound waves can also be transmitted through the skull. Two mechanisms are possible:

1. In the first mechanism, compressional waves acting on the skull deform the incompressible perilymph via the round or oval window. Because the elasticity of the two windows differs, this induces movement of the endolymph, which in turn causes motion of the basilar membrane.
2. The second mechanism is based on the movement of the ossicles, which produces motion only in the scala vestibuli. In this mechanism, basilar membrane motion arises from translational movements generated by inertia.

Bone conduction is typically 30–50 dB less effective than air conduction, which is particularly evident when both ears are blocked. While accurate, direct bone stimulation is considerably less effective than air-mediated stimuli under normal conditions.

Range of Sensitivity

Mechanical vibrations in the inner ear hair cells induce changes in membrane potentials along the conductive pathways and in higher auditory centers. Human hearing can detect frequencies ranging from approximately 16 Hz to 25,000 Hz and sound pressures (expressed in pascals, Pa) from 20 μ Pa to 20 Pa. This represents an extraordinary detectable range of one million-fold. The thresholds of audibility are

frequency-dependent, with the lowest thresholds occurring between 1,000 and 6,000 Hz and increasing at lower and higher frequencies.

For practical purposes, sound pressure levels are expressed in decibels (dB), a logarithmic scale corresponding to perceived intensity relative to the hearing threshold. Thus, 20 μ Pa corresponds to 0 dB. A tenfold increase in sound pressure corresponds to an increase of 20 dB according to the formula:

$$L_x = 20 \log_{10} \left(\frac{P_x}{P_0} \right) \quad L_x = 20 \log_{10} P_x$$

where:

- L_x = sound pressure level in dB
- P_x = sound pressure in pascals
- P_0 = reference sound pressure (2×10^{-5} Pa, the threshold of hearing)

The frequency discrimination threshold, i.e., the smallest detectable difference in frequency, ranges from 1.5 Hz to 500 Hz, with a relative difference of about 0.3% at high frequencies. Near the threshold of hearing, the sound-pressure discrimination threshold is approximately 20%, whereas at high sound intensities, differences of less than 2% can be detected. If two tones differ by only a very small frequency, a single pitch is perceived. The perceived pitch is intermediate between the two sources, but its intensity may vary. If two acoustic stimuli have similar frequencies but different intensities, a masking effect occurs. If the difference in sound pressure is sufficiently large, masking is complete, and only the louder tone is perceived. Localization of acoustic stimuli depends on the time interval between stimulus arrival at each ear, requiring intact binaural hearing. The minimal detectable delay is approximately 3×10^{-5} seconds. Localization is facilitated by the head-shadow effect, which creates intensity differences between the two ears.

The remarkable ability of humans to resolve complex acoustic stimuli arises from frequency decomposition by the inner ear and frequency analysis by the brain. These mechanisms allow individual sound sources, such as separate musical instruments in a full symphonic orchestra, to be distinguished and identified. Audiometric methods enable the assessment of auditory sensitivity and early detection of pathologies.

Audiometric Methods

Subjective Methods: Tone audiometry and speech audiometry.

Objective Methods: Otoacoustic emissions, impedancemetry, and BERA (Brainstem Auditory Evoked Response).

The auditory system has a significant impact on both health and psychological well-being. Impaired hearing or auditory problems can lead to depression, social isolation, stress, and learning difficulties. Therefore, maintaining hearing health is essential.

There are two main types of hearing loss:

1. **Conductive (middle ear):** caused by otitis, ossicular damage, or cerumen impaction.
2. **Sensorineural (inner ear):** caused by damage to the Organ of Corti, noise-induced injury, or neuropathies.

Conclusion

In conclusion, the study of the physical foundations of the auditory system not only deepens theoretical knowledge but also plays a crucial role in practical medicine, the development of diagnostic and therapeutic technologies, and the preservation of human health. Experimental studies have shown that exposure to certain solvents under specific conditions can lead to hearing impairments. Research conducted in humans indicates that such effects may arise following widespread occupational exposures. Synergistic interactions between noise and chemical agents have been observed in both human and animal experimental studies. Some heavy metals can affect hearing, although most do so only at exposure levels that cause overt systemic toxicity. For lead, minor effects on hearing thresholds have been observed at levels well below occupational exposure limits. Currently, no specific ototoxic effects of asphyxiants have been documented; however, carbon monoxide may enhance the audiological impact of noise. In this article, we utilized literature on independent learning to explore methods for studying the topic. Observations and experiments indicate that the deeper and more extensively students engage in independent learning, the more their critical thinking, reasoning, and interest in science improve. Presenting material in a clear and organized manner also contributes to the enhancement of educational quality. Thus, in the study of the physical foundations of the auditory system, employing independent learning methods and utilizing relevant literature proves to be an effective approach.

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