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CHARACTERIZATION OF MODE LOCALIZATION OF MICRO-SIZED TWO-SEGMENT TIMOSHENKO BEAMS WITH DIFFERENT MATERIALS USING THE FINITE ELEMENT METHOD

Abstract

Mode localization is a phenomenon observed in dynamic systems with weakly coupled elements, in which a small change in system parameters leads to a considerable concentration of vibration amplitude or vibration energy within a limited region instead of being distributed across the entire system. In this study, we focus on analyzing the mode localization characteristics of a two-segment beam structure made of different materials using the finite element method associated with energy criteria to evaluate the degree of mode localization. Timoshenko's beam theory is used in establishing the finite element equations. The advantage of using Timoshenko beams is that it can capture the shear effect in case of our beam because one of the two beam segments has a short length, while the cross-section remains constant, resulting in a relatively small slenderness ratio for the shorter segment, which is not suitable when using Euler-Bernoulli beam theory. In the framework of the free vibration problem, the proposed kinetic energy indicator is based on the ratio of kinetic energy between two beam segments, to assess the degree of mode localization along the beam length. The kinetic energy ratio depending on the beam's parameters is explored in detail.

Keywords:

mode localization, coupled systems, Timoshenko beam, finite element, energy ratio.

1. Introduction

Mode localization is a dynamic phenomenon arising from systems with weakly coupled components, where the amplitude or energy of vibration is concentrated in a particular region of the system [1, 2]. The concept of mode localization was first introduced by Anderson [3] when studying the localization characteristics of electrons in a disordered lattice. Throughout the 20th and early 21st centuries, Anderson's principle has been applied to explain many physical phenomena in various fields, related to the localization of energy in a region rather than its uniform distribution across all regions of a system with coupled elements, such as in acoustics [4], optics [5], chemistry [6], aerospace engineering [7].

In the field of structural engineering, particularly large-scale structures, a characteristic of mode localization is the confinement of energy within one or more structural elements, such as within a particular segment of a multi-span beam [8]. In [9], Bouzit and Piere examined the dynamic irregularities of multi-span beams to study the mode localization effect. They observed that if there exists a difference between the lengths of the beam spans, this leads to the dynamic response of the beam being localized within a small region along the beam's length. Another study by Pierre et al. [10] presented the vibration localization properties in a multi-span beam system, both theoretically and experimentally. The results showed that localization occurs when there is a small deviation in the lengths of the beam spans. These authors also proposed a criterion for predicting the appearance of strongly localized modes. Another aspect of localized systems can be found in a notable study by Hodges and Woodhouse [11]. They found in pendulum systems that even a small deviation in parameters within a periodic vibration model can lead to energy localization within the system.

In the field of micro- and nano-scale structures, recent progress in the fabrication technology of modern sensors has made, in part, thanks to new methods that increase the sensitivity of sensors compared to traditional methods based on frequency shift [12]. These sensors typically utilize beam-like structures or combinations of beams to detect some changes acting on the system structure. Unlike traditional single-degree-of-freedom resonant sensors that rely primarily on the principle of frequency shift during measurement, sensors based on the model localization principle significantly increase the sensitivity of the system. This sensitivity is monitored through the change rate of modal shapes of a vibrating system in which a small change in a particular parameter causes a breaking of the initial symmetry of the system. Consequently, the energy concentration in certain modes of the system occurs. One of the effective applications of mode localization was discussed in the study by Spletzer et al. [13] for MEMS structures. That structure is a system of two cantilever beams connected to each other. At the end of one beam has a small mass, i.e., a disturbance in the beam's mass compared to the two original identical beams. The occurrence of the disturbance significantly affects the shape of the vibration mode and therefore allows for efficient detection of mass changes. The phenomenon of mode localization, arising from mode interaction, offers a potential solution to overcome the limitations of traditional sensor technology, as seen in the research of Wang et al. [14]. They present a decoupled-decomposition noise analysis model, which is applied to achieve high resolution in a mode-localized tilt sensor based on a coupled resonator closed-loop circuit. Zang et al. [15] proposed virtually coupled resonators with modal dominance for improved sensitivity and bandwidth. Their experimental results validate the feasibility of virtually coupled resonators and the double-closed-loop control. A notable result demonstrates a 2.7-fold improvement in sensitivity and at least a four-fold enhancement in bandwidth relative to weakly coupled resonators with identical parameters.

The MEMS structures discussed above are largely based on the Euler-Bernoulli beam theory. One drawback of the Euler-Bernoulli beam theory is that if the beam structure of the MEMS system becomes shorter and the height of beam's cross section becomes thicker, the shear effect needs to be taken into account [16]. Thus, in this study, the authors use the Timoshenko beam theory to investigate the mode localization effect of a micro-sized beam composed of two segments, each made from a different material. In MEMS systems using mode localization, a small change in system parameters can lead to a certain change in the localization properties. A feature of traditional MEMS structures is the use of at least two coupled beams, and their link may be a weak one. Our study proposes that even using only one beam with two different materials, the mode localization phenomenon is observed, i.e., there is a nonuniform energy distribution on the two segments of the beam. The mode localization properties are investigated using the finite element method for the Timoshenko beam associated with energy indicator to assess localization level of beam vibrations.

2. Timoshenko beam model and kinetic energy indicator of mode localization

Consider a micro-sized cantilever beam with total length L_t, composed of two segments made of two different materials. The first segment has length L_{b1}, elastic modulus E_1, mass density ρ_1; and the second one has length L_{b2}, elastic modulus E_2, mass density ρ_2. We introduce two parameters $\alpha = E_2 / E_1$, $\beta = \rho_2 / \rho_1$ characterizing the ratios of the elastic moduli and mass densities of segment 2 to segment 1. The cross-sections of the two beam segments are assumed to be the same, $A = b \times h$, where b is the width and h is the thickness of the beam. The coordinate system of the beam is chosen such that the x-axis is directed along the length of the beam, the z-axis is directed downwards and perpendicular to the x-axis, as shown in Fig. 1.

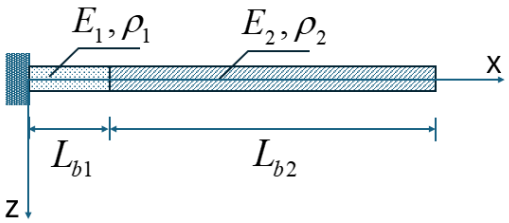

Figure 1 – Timoshenko micro-sized beam model with two segments made of two different materials

Within the framework of this research, Timoshenko's beam theory is used to investigate the vibration characteristics of the beam. Let $u_x^{(i)}(x,z,t)$, $u_z^{(i)}(x,z,t)$ be displacement fields in x, z -directions of the *i*-th segment where the index *i*=1 shows the first one with $0 \le x \le L_{b1}$, and the index *i*=2 presents the second one with $L_{b1} \le x \le L_t$ along beam's axis. The fields $u_x^{(i)}(x,z,t)$, $u_z^{(i)}(x,z,t)$ can be represented as follows [17]:

$$\begin{aligned} u_x^{(i)}(x,z,t) &= -z\theta_i(x,t) \\ u_z^{(i)}(x,z,t) &= w_i(x,t) \end{aligned} \tag{1}$$

where $\theta_i(x,t)$, $w_i(x,t)$ are rotation and deflection of beam axis, respectively. In each beam segment, deflection and rotation angle are considered as two independent variables. In Euler-Bernoulli beam theory, the rotation angle is approximated as the derivative of deflection. For free vibration, we assume that $w_i(x,t)$, $\theta_i(x,t)$ $(i=1,2)$ can be represented via the modal shape functions $W_i(x)$, $\Theta_i(x)$ as follows:

$$w_i(x,t) = W_i(x)\cos(\omega t),\ \theta_i(x,t) = \Theta_i(x)\cos(\omega t) \tag{2}$$

where ω is the natural vibration frequency of the beam. The mode properties may be revealed through the distribution of vibrational energy in the two beam segments. Kinetic energy is one of the important indicators to be considered when determining which beam segment is dominant; this property is referenced as an indicator of energy localization. Therefore, vibration localization of the beam will be calculated through the kinetic energy ratio between two segments with various system parameters. The kinetic energy of the beam is the total kinetic energy of the two beam segments:

$$T = T_{b1} + T_{s1} + T_{b2} + T_{s2} \tag{3}$$

where T_{b1}, T_{s1}, T_{b2}, T_{s2} are kinetic energy contributions due to bending and shearing of segments 1 and 2, respectively:

$$\begin{aligned} T_{b1} &= \frac{1}{2}\rho_1 A\omega^2 \sin^2(\omega t)\int_0^{L_{b1}} W_1^2(x)\,dx,\ T_{s1} = \frac{1}{2}\rho_1 I_y \omega^2 \sin^2(\omega t)\int_0^{L_{b1}} \Theta_1^2(x)\,dx \\ T_{b2} &= \frac{1}{2}\rho_2 A\omega^2 \sin^2(\omega t)\int_{L_{b1}}^{L_t} W_2^2(x)\,dx,\ T_{s2} = \frac{1}{2}\rho_2 I_y \omega^2 \sin^2(\omega t)\int_{L_{b1}}^{L_t} \Theta_2^2(x)\,dx \end{aligned} \tag{4}$$

For the Timoshenko beam model under consideration, the ratio η_{TB} of the kinetic energy of segment 2 to segment 1 is introduced:

$$\eta_{TB} = \frac{T_{b2}+T_{s2}}{T_{b1}+T_{s1}} = \beta\frac{\int_{L_{b1}}^{L_t} W_2^2(x)\,dx + r_y^2\int_{L_{b1}}^{L_t}\Theta_2^2(x)\,dx}{\int_0^{L_{b1}} W_1^2(x)\,dx + r_y^2\int_0^{L_{b1}}\Theta_1^2(x)\,dx} \tag{5}$$

where $r_y = \sqrt{I_y / A}$ is radius of gyration of beam's cross section. The ratio η_{TB} is considered as an indicator to assess the degree of localization of vibration energy on the two beam segments. In the case of the Euler-Bernoulli beam, because shear strain is not considered in Eq. (5), the kinetic energy component due to shear strain will be ignored. As a result, we obtain the energy ratio of segment 2 to segment 1 for the Euler-Bernoulli beam as follows:

$$\eta_{EB} = \beta \frac{\int_{L_{b1}}^{L_t} W_2^2(x)\,dx}{\int_0^{L_{b1}} W_1^2(x)\,dx} \tag{6}$$

where the finite integrals are calculated on two different beam segments, in which the integrands are functions corresponding to the *j*-th modal shapes.

3. Free vibration equation of beam using the finite element method

Timoshenko's beam theory is known as an extension of Euler-Bernoulli beam theory. The number of degrees of freedom in the equation of motion, thus, increases compared to the Euler-Bernoulli beam. The beam segments 1 and 2 are divided into n_1, n_2 elements, respectively. The nodes are numbered from 1 to $n_1 + n_2 + 1$, where segment 1 is numbered from 1 to $n_1 + 1$ and segment 2 is taken from $n_1 + 1$ to $n_1 + n_2 + 1$. Assume that the elements on each beam segment are of the same length. For beam segment 1, the element length is $L_1 = L_{b1} / n_1$. The element length in segment 2 is $L_2 = L_{b2} / n_2$. The degrees of freedom of each element in each segment are illustrated in Figure 2. The element's nodal displacement vector is denoted as $\{q\}_e = \{w_e \quad \theta_e \quad w_{e+1} \quad \theta_{e+1}\}^T$ ($e = 1, 2, ..., n_1 + n_2$). Combined nodal displacement vector in the global coordinate is $\{q\} = \{w_1 \quad \theta_1 \quad w_2 \quad \theta_2 \ldots w_{n_1+n_2} \quad \theta_{n_1+n_2} \quad w_{n_1+n_2+1} \quad \theta_{n_1+n_2+1}\}^T$ for which the boundary between two segments is a common node.

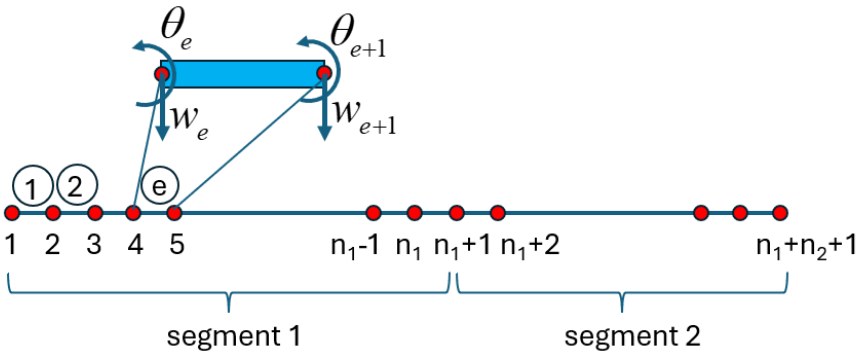

Figure 2 – Illustration of degree of freedoms of elements and numbered nodes along the length of the beam

Using the standard finite element method for the Timoshenko beam with exact shape functions found from the governing equation of free vibration of beam [18], we obtain an equation of motion for the beam through the degrees of freedom of the nodes as follows:

$$[M]\{\ddot{q}\} + [K]\{q\} = \{0\} \tag{7}$$

where $[M], [K]$ are global mass and stiffness matrices after assembling element's mass and stiffness

matrices, respectively. The size of these matrices is $2\left(n_1+n_2+1\right)\times 2\left(n_1+n_2+1\right)$. Because the beam's boundary is clamped at node 1, the deflection w_1 and rotation angle θ_1 are both zeros. By imposing this condition, we obtain the following reduced equation of motion:

$$\left[\bar{M}\right]\left\{\ddot{\bar{q}}\right\}+\left[\bar{K}\right]\left\{\bar{q}\right\}=\left\{0\right\} \tag{8}$$

where $\left[\bar{M}\right]$, $\left[\bar{K}\right]$ are the reduced global mass and stiffness matrices with size $2\left(n_1+n_2\right)\times 2\left(n_1+n_2\right)$; $\left\{\bar{q}\right\}$ is a reduced global nodal displacement vector after removing the degree of freedom of the boundary node 1. Assume that the vector $\left\{\bar{q}\right\}$ can be represented as a solution of periodic form in time:

$$\left\{\bar{q}\right\}=\left\{\bar{q}_0\right\}\cos\left(\omega t\right) \tag{9}$$

where $\left\{\bar{q}_0\right\}$ is a amplitude vector. By substitution of solution (9) into Eq. (8) yields the following homogeneous algebraic equation for $\left\{\bar{q}\right\}$:

$$\left(\left[\bar{K}\right]-\omega^2\left[\bar{M}\right]\right)\left\{\bar{q}\right\}=\left\{0\right\} \tag{10}$$

Eq. (10) can be transformed into the following equivalent representation:

$$\left(\left[\bar{M}\right]^{-1}\left[\bar{K}\right]-\omega^2\left[I\right]_{2(n_1+n_2)}\right)\left\{\bar{q}\right\}=\left\{0\right\} \tag{11}$$

where the notation $\left[\bar{M}\right]^{-1}$ is an inverse matrix of the mass matrix $\left[\bar{M}\right]$, $\left[I\right]_{2(n_1+n_2)}$ is a unit matrix with size $2\left(n_1+n_2\right)\times 2\left(n_1+n_2\right)$. The Eq. (11) shows that the quantity ω^2 is a eigenvalue of the squared matrix $\left[\bar{M}\right]^{-1}\left[\bar{K}\right]$ and is the solution of the following characteristic equation:

$$\det\left(\left[\bar{M}\right]^{-1}\left[\bar{K}\right]-\omega^2\left[I\right]_{2(n_1+n_2)}\right)=0 \tag{12}$$

By solving the problem of eigenvalue and eigenvector of the matrix $\left[\bar{M}\right]^{-1}\left[\bar{K}\right]$, we obtain a vector of set of frequencies $\left\{\omega_1 \quad \omega_2 \quad \ldots \quad \omega_{2(n_1+n_2)}\right\}^T$ with $2\left(n_1+n_2\right)$ elements and a set of eigenvectors $\left\{V_i\right\}_{i=1,2,\ldots,2(n_1+n_2)}$. The eigenvector $\left\{V_i\right\}$ is separated into a vector $\left\{W^{(i)}\right\}$ corresponding to the deflection and a vector $\left\{\Theta^{(i)}\right\}$ corresponding to the rotation angle of the beam. The vector $\left\{W^{(i)}\right\}$ has elements located at odd-index positions in the eigenvector $\left\{V_i\right\}$, while the vector $\left\{\Theta^{(i)}\right\}$ has elements located at even-index positions in the eigenvector $\left\{V_i\right\}$. In this study, we will investigate the behavior of the vibration modes to clarify the localized nature of the vibration of the two-segment cantilever beam under consideration based on the characteristics of the vibration energy of the modes.

4. Numerical results and discussions

In this subsection, we consider a cantilever beam with total length $L_t=460\ \mu\text{m}$ and cross-sectional dimension $b\times h=49\,\mu\text{m}\times 2.3\,\mu\text{m}$. The first segment of the beam is made of silicon material with elastic

modulus $E_1 = 130$ GPa, mass density $\rho_1 = 2329$ kg/m^3, and Poisson's ratio $\mu_1 = 0.28$. (For silicon material, the elastic modulus E_1 is taken in the (100) direction in the crystal structure). The second segment is made of silicon carbide, abbreviated as SiC, which has a larger elastic modulus than the silicon material. In our calculations, we use coefficient value $\alpha = 2.66$, i.e. $E_2 = \alpha E_1 = 345.8$ GPa; coefficient value $\beta = 1.66$, i.e. $\rho_2 = \beta\rho_1 = 1.38 \times 2329 = 3214.02$ kg/m^3. Poisson's ratio of the SiC material is taken as $\mu_2 = 0.19$. In case $\alpha = 1$ and $\beta = 1$, we obtain homogeneous material for the two segments of the beam, i.e. the two-segment beam problem becomes a homogeneous beam problem with a single material. Table 1 shows that the first and second vibration frequencies calculated using the Timoshenko beam FEM model and Euler-Bernoulli beam FEM model are in a good agreement with those obtained from exact solutions [20] in previous publications, and experimentally measured frequencies [19]. Because the considered beam is relatively slender and thin, the results of Timoshenko's beam theory and Euler-Bernoulli's beam theory differ only slightly. The difference increases if the beam length is reduced and the beam thickness is increased.

Five modal shapes of vibration of the considered micro-cantilever with two material segments are illustrated in Fig. 3 for beam deflection. The vibration modes will be normalized according to the mass of a reference beam of length L_t, mass density ρ_1, i.e. $\{V_i\}^T [\bar{M}] \{V_i\} = m_{ref}$ with $m_{ref} = \rho_1 A L_t$.

Table 1

Comparison of the first and second vibration frequencies in the case of a homogeneous beam material using different approaches

	Experiment [19] (kHz)	Analytical [20] (kHz)	EB-FEM (kHz)	TB-Present (kHz)
1st freq.	12.80	13.1184	13.1184	13.1181
2nd freq.	78.78	82.2113	82.2113	82.1996

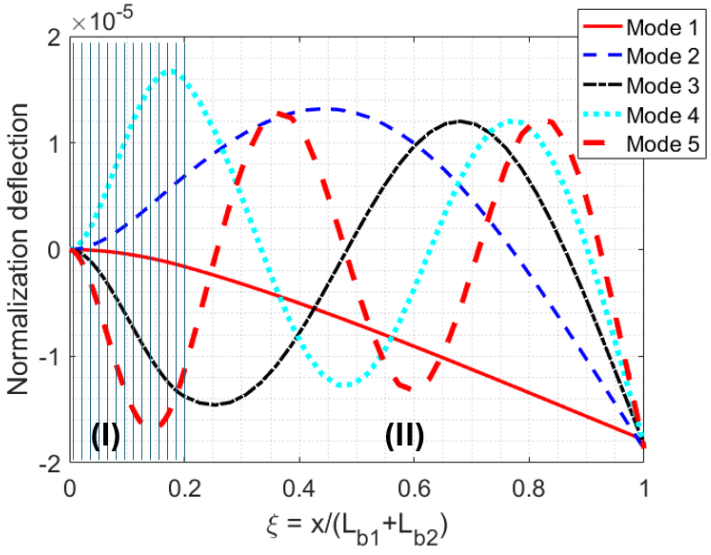

Figure 3 – The first five eigenmodes of deflection in cantilever beam vibration. (I): the first segment; (II): the second segment

In Fig. 3, along the length of beam, two regions are separated, one presents for the first segment, denoted as region (I) with $0 \le \xi = x / L_t \le \xi_1 = L_{b1} / L_t$; the second region (II) with

$\xi_1 = L_{b1} / L_t \le \xi = x / L_t \le 1$; ξ_1 is taken as $\xi_1 = 0.2$. The first vibration mode has the greatest deflection at the free end of the beam. The first mode has no antinodes, while modes 2, 3, 4, 5 have 1, 2, 3, 4 antinodes respectively. Modes with antinodes will have zero-points at which the eigenvalue is zero. This is known similarly to the free vibration of a conventional cantilever beam with a homogeneous material. The difference here compared to a homogeneous material beam is that the influence of the two beam materials leads to different energy distribution on the two beam segments. With parameters $\alpha = 2.66$, $\beta = 1.38$, they show that segment 1 has a much "softer" elastic modulus than segment 2, and a lower mass density than segment 2; thus, for a cantilever beam, the vibration properties will be skewed towards one of the two segments. Physically, based on the indicator in equation (5), energy localization will appear on the two beam segments where one segment will occupy a significantly energy level than the other.

In Fig. 4, for the same elastic modulus, increasing the mass density ratio β leads to a decrease in first frequency of the beam. In other words, increasing the density of the second segment has a softening effect on the structure, making it more susceptible to low-frequency vibrations in the range of approximately 5.5 kHz to 17.5 kHz. The position at which $\beta = 1$ shows that the mass density of the two beam segments is the same. If parameter β is much smaller than 1, the beam will vibrate at a relatively high frequency, and the highest frequency occurs when the ratio β is taken as the lower bound, i.e. $\beta = 0.4$, within the considered range.

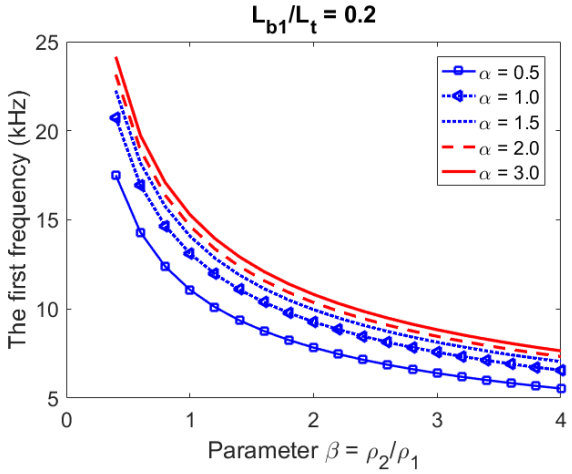

Figure 4 – Curves of the first frequency depending on the ratio $\beta = \rho_2 / \rho_1$ with different values of parameter α and with the ratio $L_{b1} / L_t = 0.2$

On the other hand, with the same mass density ratio, increasing the ratio α will increase the first vibration frequency, that means the beam will become stiffer. In Fig. 4, the value $\alpha = 1$ shows the frequency curve of the beam with two segments having the same Young's modulus. Thus, two opposite trends can be observed. On the one hand, increasing the mass density reduces the frequency of vibrations of the system, indicating a softening effect. On the other hand, increasing Young's modulus ratio raises the natural frequencies, reflecting a stiffening effect. These completing influences may be referred to as a softening-stiffening effect associated with variations in beam material properties. Specially, an increase in mass density ratio softens the dynamic response of the beam, whereas an increase in Young's modulus ratio stiffens it. Such completing effects are absent in homogeneous beams where the material properties remain uniform throughout the structure.

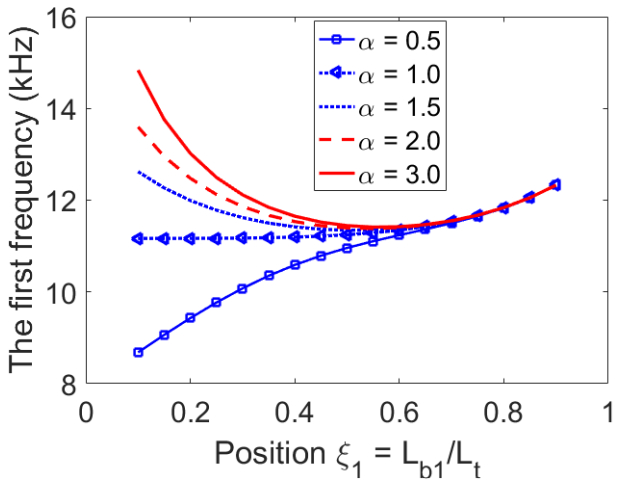

Figure 5 – Curves of the first frequency depending on beam length ratio $\xi_1 = L_{b1} / L_t$ with different values of modulus ration $\alpha = E_2 / E_1$ and with the ratio $\beta = 1.38$

Vibration localization properties can be revealed through the frequency distribution when changing the common boundary point between two beam segments, i.e., changing the ratio of the length of the first segment to the total beam length. In Fig. 5, the first frequency has a relatively different distribution along the beam length when changing the ratio parameter α from 0.5 to 3.0. For the considered parameters, when $\alpha = 1.5,\ 2.0,\ 3.0$, the first frequency even has an extreme point at a specified position along the beam length. This means that there exists a position corresponding to the ratio $\xi_1 = L_{b1} / L_t$ such that the first frequency of the beam reaches its minimum value, i.e., the beam is in a relatively "soft" state compared to other positions. This is very useful in designing highly sensitive sensors based on frequency distribution. This characteristic is a result of vibration localization when the beam material is no longer homogeneous. This suggests that it can provide an alternative design approach in comparison to the traditional sensor designs with homogeneous materials. As the ratio ξ_1 tends to 1, the frequency curves corresponding to the parameter α approach to each other's, that is, they are asymptotically close to the frequency value of the homogeneous material.

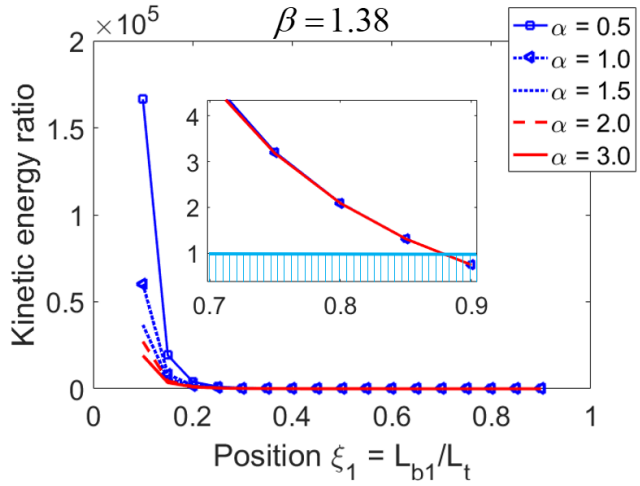

Figure 6 – Kinetic energy ratio between two segments depending on the beam length parameter $\xi_1 = L_{b1} / L_t$ with various values of modulus ratio $\alpha = E_2 / E_1$ and with the ratio $\beta = \rho_2 / \rho_1 = 1.38$

The localized nature of the vibration is more clearly reflected through the energy indicator η_{TB}. Fig. 6 illustrates the curves of the energy ratio changing with various location $\xi_1 = L_{b1} / L_t$ under different values of parameter α; the value β is taken as $\beta = 1.38$. The emphasis here is on the value $\beta = 1.38$ leading to the fact that the ratio η_{TB} has a relatively large value when location ξ_1 close to 0, and almost on the interval [0.1, 0.9] the value of η_{TB} is greater than 1; only when value ξ_1 is larger than about 0.87 the ratio η_{TB} is less than 1. This reflects that, with ξ_1 is less than 0.87, the kinetic energy is almost concentrated in segment 2, whereas if value ξ_1 is larger than 0.87, the kinetic energy gradually shifts to predominating in segment 1. This energy difference shows that the degree of localization is relatively clear in cantilever beams without homogeneous materials, for example, the material in segment 2 has a larger elastic modulus than segment 1.

In Fig. 7, when exploring the ratio η_{TB} with the value $\beta = 0.4$, the degree of energy localization is also relatively clear: energy is concentrated in segment 2 if ξ_1 is less than 0.75, while a reversal of energy concentration occurs if ξ_1 is greater than 0.75. The shift of ξ_1 from 0.87 to 0.75 is considered not large, however, this is a useful range to understand the reversal of energy concentration between the two beam segments when designing cantilever beam sensors with different parameters.

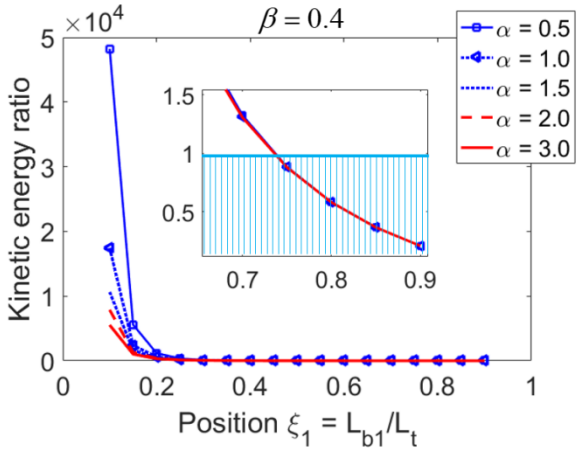

Figure 7 – Kinetic energy ratio between two beam segments depending on the parameter $\xi_1 = L_{b1} / L_t$ with various values of modulus ration $\alpha = E_2 / E_1$ and with the ratio $\beta = \rho_2 / \rho_1 = 0.4$

5. Conclusions

Mode localization has emerged as an attractive sensing mechanism because it can achieve significantly higher sensitivity than conventional frequency-shift-based resonant sensors in many modern sensing applications. In this study, the authors obtained the following results:

- A kinetic energy-based approach is proposed to evaluate the degree of localized vibration of a cantilever microbeam with two different material segments.

- The study reveals a novel physical effect observed related to the change in vibration frequency of the beam when changing Young's modulus and mass density ratios of the two beam segments. The observed vibration properties are referenced as a stiffening-softening effect dependent on the beam material parameters.

- When changing Young's modulus parameter, there exists a beam configuration at which the first frequency can be minimized, meaning that beams can be designed with a specified ratio of the first segment

length to the total length to minimize the first frequency.

- It is shown that the concentration of kinetic energy is mainly located in the second segment of the beam, with the ratio of the first segment length to the total length being less than 0.75 to 0.87, depending on the value of Young's modulus ratio of the two beam materials.

In this study, the authors have used the Timoshenko beam model to evaluate the energy localization and vibration frequency of micro-sized beams and verified it against known results. However, at the micro-scale level, the Timoshenko beam model needs to consider the influence of the "internal size" parameter, i.e., the intrinsic micro-scale parameter of the beam, to achieve a more accurate quantitative assessment, helping to design more reliable sensors.

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ПОВЫШЕНИЕ ПРОИЗВОДИТЕЛЬНОСТИ ИНТЕРНЕТА ВЕЩЕЙ В БЕСПРОВОДНЫХ И МОБИЛЬНЫХ СЕТЯХ ЗА СЧЁТ ИНТЕГРАЦИИ ИМЕНОВАННЫХ СЕТЕЙ (NDN) И ГРАНИЧНЫХ ВЫЧИСЛЕНИЙ

Аннотация

Статья посвящена новой адаптивной структуре NDN-Edge Computing, которая динамически оптимизирует извлечение данных, кэширование и распределение вычислительных ресурсов

Ключевые слова:
интернет вещей, именованные сети (NDN), граничные вычисления.

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ENHANCING IOT PERFORMANCE IN WIRELESS AND MOBILE NETWORKS THROUGH NAMED DATA NETWORKING (NDN) AND EDGE COMPUTING INTEGRATION

Abstract

This paper proposes a novel adaptive NDN-Edge Computing framework that dynamically optimizes data retrieval, caching, and computational resource allocation.

Keywords:
IoT, Named Data Networking (NDN), Edge Computing, Optimization, Wireles

Введение

Бурное развитие интернета вещей (IoT, Internet of Things) и киберфизических систем привело к появлению приложений, предъявляющих исключительно высокие требования к беспроводной связи: сверхнадёжность, задержки на уровне миллисекунд и способность работать в динамически изменяющейся среде. Традиционные IP-сети, основанные на адресации устройств, часто не справляются с этими условиями, особенно в сценариях с высокой мобильностью и большим объемом данных. В ответ на этот вызов сформировалось направление по интеграции Именованных сетей (NDN, Named Data Networking) и граничных вычислений. NDN предлагает контент-ориентированную парадигму, фокусируясь на извлечении данных по именам, а не адресам, что идеально подходит для приложений IoT. Граничные вычисления, в свою очередь, переносят обработку данных на периферию сети, снижая задержку и нагрузку на магистральные каналы. [1, 3, 8].

Однако, несмотря на преимущества, их интеграция остается неоптимальной из-за проблем с динамическим распределением ресурсов, эффективностью маршрутизации и устойчивостью в условиях неопределенности сети. Большинство существующих решений рассматривают управление, связь и оценку как слабо связанные модули. [2, 4].

Цель данной статьи - представить целостный взгляд на адаптивную структуру NDN-Edge Computing для повышения производительности IoT в беспроводных и мобильных сетях. Мы опишем архитектуру, систематизируем показатели эффективности, выделим фундаментальные компромиссы и проиллюстрируем их на практическом примере. В заключении обсудим ключевые вызовы и перспективные исследования. [3, 8].

1. Архитектура и методология предложенной структуры NDN-Edge Computing

Предлагаемая структура включает три основных уровня, каждый из которых вносит вклад в функционирование замкнутого контура управления и обработки данных.

1.1. Компоненты системы

1.Уровень устройств IoT: Состоит из сенсорных узлов, интеллектуальных камер и мобильных устройств IoT. Этот уровень генерирует данные в реальном времени и передает запросы, используя механизм Interest-пакетов NDN, вместо традиционной IP-адресации.

2.Уровень граничных вычислений: Состоит из распределенных граничных узлов, оснащенных кэшами NDN и облегченными вычислительными ресурсами. Он обрабатывает запросы локально, используя внутрисетевое кэширование и интеллектуальную пересылку, что критически важно для снижения задержки.

3.Уровень основной сети и облака: Служит запасным вариантом для извлечения данных, когда граничные кэши не могут выполнить запрос, снижая зависимость от центральных серверов и улучшая масштабируемость.

В отличие от традиционной IP-пересылки, интеграция NDN-Edge Computing работает следующим образом: устройства IoT отправляют Interest-пакеты, запрашивая именованный контент. Граничный узел проверяет свой кэш на наличие данных. Если контент найден, ответ отправляется немедленно. Если нет, запрос интеллектуально пересылается с использованием базы информации пересылки (FIB, Forwarding Information Base) NDN для извлечения его из другого граничного узла или облака. После извлечения пакет данных кэшируется на промежуточных узлах для будущего использования. [4, 7, 8].

1.2. Методы оптимизации

Основной вклад работы заключается в разработке новой адаптивной структуры, которая

оптимизирует извлечение данных, кэширование и распределение вычислительных ресурсов. Для этого используются три ключевых подхода:

- динамическое распределение ресурсов: Структура динамически адаптируется к условиям трафика в реальном времени и требованиям пользователей, обеспечивая эффективное распространение и обработку данных.

- многокритериальная оптимизация: В отличие от предыдущих статических моделей, мы вводим модель, которая одновременно минимизирует задержку, максимизирует надежность и оптимизирует энергопотребление. Для решения этой задачи используются Парето-ориентированные методы (NSGA-II, Non-dominated Sorting Genetic Algorithm II), оптимизация роя частиц (PSO, Particle Swarm Optimization), генетические алгоритмы (GA, Genetic Algorithms) и нечеткая логика. Пользователи могут задавать приоритеты для разных метрик.

- робастная оптимизация: Включает механизм, обеспечивающий устойчивость сети к непредсказуемым всплескам трафика, динамическим изменениям топологии и отказам граничных узлов. Этот подход гарантирует, что сеть остается стабильной и эффективной даже при неблагоприятных условиях. [5, 10].

1.3. Показатели эффективности

Для оценки беспроводной локальной сети (LAWN, Local Area Wireless Network) необходимы метрики нескольких уровней:

- Метрики управления/сети: Задержка (время от запроса до получения данных), надежность (вероятность успешной доставки пакета), энергопотребление и коэффициент попадания в кэш.

- Метрики оценки: Среднеквадратичная ошибка (MSE) оценки состояния, частота обновлений данных. [6, 8].

2. Компромиссы «производительность-ресурсы»

В предлагаемой системе, как и в любой сложной сети, невозможно одновременно минимизировать все метрики - существуют фундаментальные компромиссы. [3].

2.1. Компромисс «задержка-энергопотребление»

Приоритизация путей с низкой задержкой часто приводит к более высокому энергопотреблению из-за повышенной сетевой активности и вычислительных накладных расходов на граничных узлах. И наоборот, стратегии энергосбережения (например, агрессивное кэширование) могут увеличить задержку. [5, 8].

2.2. Компромисс «надежность-энергопотребление»

Для повышения надежности и устойчивости к отказам используется избыточность (многопутевая пересылка, дублирование запросов). Это повышает вероятность успешной доставки, но значительно увеличивает потребление энергии и загрузку сети. [2, 4].

2.3. Компромисс «задержка-надежность»

В условиях высокой нагрузки для минимизации задержки система может отказываться от использования резервных путей, что снижает надежность. Структура позволяет динамически балансировать эти параметры в зависимости от требований приложения (например, для промышленной автоматизации важен компромисс, ориентированный на задержку, а для мониторинга здоровья - на надежность). [3, 8].

3. Пример из практики: умная система видеонаблюдения

Рассмотрим типовой сценарий IoT. Развертывание включает 50 IoT-камер, каждая из которых передает видеопоток, подключенных к 10 граничным узлам, выполняющим аналитику видео в реальном времени. [4, 8].

3.1. Особенности работы NDN-Edge

Камеры отправляют Interest-пакеты, запрашивая конкретные фрагменты видео. Граничные узлы кэшируют часто запрашиваемые данные. Анализ видео выполняется локально на границе, что значительно снижает нагрузку на центральный сервер. При выходе из строя граничного узла система динамически перенаправляет запросы на другие узлы. [2, 7].

3.2. Адаптивная структура и результаты

Предлагаемая структура значительно превзошла традиционные IP-архитектуры. Ключевые улучшения:

- Снижение задержки на 25%: Достигнуто за счет внутрисетевого кэширования и адаптивной пересылки Interest-пакетов, особенно в условиях высокого трафика.

- Улучшение энергоэффективности на 15%: Достигнуто за счет устранения ненужных передач данных и оптимизации распределения вычислительных задач на границе.

- Увеличение коэффициента попадания в кэш на 20%: Означает, что больше запросов данных выполнялось непосредственно из граничного хранилища, экономя полосу пропускания.

- Сохранение высокой надежности (95%): Система оставалась работоспособной даже при отказе до 30% граничных узлов, демонстрируя свою устойчивость. [5, 6].

4. Перспективные направления исследований

4.1. Интеграция с блокчейном для децентрализованного управления доверием

Хотя интеграция блокчейна предлагается для повышения безопасности, она вносит вычислительные накладные расходы. Будущие работы должны исследовать облегченные альтернативы, такие как иерархические архитектуры блокчейна и механизмы консенсуса с низким энергопотреблением (например, Proof of Authority), чтобы сделать их применимыми для ресурсно-ограниченных устройств IoT. [1, 7].

4.2. Адаптивная маршрутизация на основе машинного обучения

Применение методов глубокого обучения с подкреплением (DRL) для обучения политик управления, которые оптимизируют компромисс между связью и точностью. Это позволит системе более интеллектуально адаптироваться к динамическим сетевым условиям. [2, 10].

4.3. Интеграция с 5G и безопасность

Необходимы легковесные криптографические протоколы и физические методы защиты. Развитие планирования, учитывающего приоритеты управления, и механизмов быстрой повторной передачи (HARQ) будет способствовать повышению надежности. [3, 9].

4.4. Децентрализованная координация

При большом числе агентов централизованный подход становится узким местом. Переход к децентрализованному управлению с прямым обменом данными между устройствами (D2D) и достижением консенсуса повысит масштабируемость системы. [4, 8].

Заключение

В статье представлена целостная архитектура адаптивной структуры NDN-Edge Computing для повышения производительности IoT в беспроводных и мобильных сетях. Описаны основные компоненты, метрики эффективности и три фундаментальных компромисса: «задержка-энергопотребление», «надежность-энергопотребление» и «задержка-надежность». На примере умной системы видеонаблюдения показана эффективность предложенной интеграции, которая позволила снизить задержку на 25%, улучшить энергоэффективность на 15% и увеличить коэффициент попадания в кэш на 20% по сравнению с обычными подходами. Обозначены четыре ключевых направления будущих исследований, среди которых особо выделяются интеграция с блокчейном, адаптивная маршрутизация на основе ИИ и децентрализованная координация. Реализация этих

направлений позволит создать масштабируемые, устойчивые и надежные системы управления для широкого круга приложений IoT. [3, 8].

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АНАЛИЗ ГОМОМОРФНОГО ШИФРОВАНИЯ НА АЛГЕБРАИЧЕСКИХ РЕШЁТКАХ

Аннотация

Статья посвящена полностью гомоморфному шифрованию как криптографическому примитиву для вычислений над зашифрованными данными. На основе LWE и Ring-LWE рассматриваются эволюция схем BGV, BFV, CKKS и TFHE, механизмы бутстрапинга и переключения модулей, а также проблемы эффективности и перспективы практического применения в защищённых облачных сервисах и машинном обучении

Цель. Систематизировать математические основы FHE на базе LWE/RLWE, проанализировать эволюцию схем BGV, BFV, CKKS и TFHE с акцентом на бутстрапинг и управление шумом, а также обосновать практическую реализуемость FHE через современные библиотеки и аппаратные ускорители для применения в защищённых облачных вычислениях и машинном обучении.

Результат. В результате проведённого анализа установлено, что полностью гомоморфное шифрование на основе решёточных задач (LWE/RLWE) прошло путь от теоретической конструкции до

практически применимых схем BGV, BFV, CKKS и TFHE, при этом ключевыми механизмами, обеспечивающими неограниченную глубину вычислений, являются бутстрапинг, переключение модулей и упаковка данных.

Ключевые слова:

гомоморфное шифрование, полностью гомоморфное шифрование (FHE), вычисления на зашифрованных данных, решёточные задачи, Learning with Errors (LWE), Ring-LWE, бутстрапинг, схемы BGV, BFV, CKKS, TFHE, управление шумом, переключение модулей, упаковка данных, постквантовая криптография, конфиденциальные вычисления, машинное обучение с сохранением приватности, облачные вычисления.

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ANALYSIS OF HOMOMORPHIC ENCRYPTION ON ALGEBRAIC LATTICES

Abstract

This article explores fully homomorphic encryption as a cryptographic primitive for computing over encrypted data. Using LWE and Ring-LWE, the evolution of the BGV, BFV, CKKS, and TFHE schemes, bootstrapping and module switching mechanisms, as well as efficiency issues and prospects for practical application in secure cloud services and machine learning are discussed.

Objective: To systematize the mathematical foundations of FHE based on LWE/RLWE, analyze the evolution of BGV, BFV, CKKS, and TFHE schemes with an emphasis on bootstrapping and noise management, and substantiate the practical feasibility of FHE using modern libraries and hardware accelerators for use in secure cloud computing and machine learning.

Result. The analysis revealed that lattice-based fully homomorphic encryption (LWE/RLWE) has evolved from a theoretical construct to practical implementations of BGV, BFV, CKKS, and TFHE schemes, with bootstrapping, module switching, and data packing being key mechanisms enabling unlimited computation depth.

Keywords

Homomorphic encryption, fully homomorphic encryption (FHE), encrypted computing, lattice problems, Learning with Errors (LWE), Ring-LWE, bootstrapping, BGV, BFV, CKKS, TFHE, noise control, module switching, data packing, post-quantum cryptography, confidential computing, privacy-preserving machine learning, cloud computing.

1. Введение

Стремительный рост объёмов цифровых данных, повсеместная миграция вычислительных процессов в облачные инфраструктуры и ужесточение требований к защите персональных данных формируют фундаментальное противоречие современной информационной безопасности: как обеспечить конфиденциальность данных в процессе их обработки? Традиционные криптографические методы, такие как AES или RSA, защищают данные на этапах хранения и передачи, однако перед выполнением любых вычислений данные должны быть расшифрованы, что создаёт уязвимость.

Гомоморфное шифрование предлагает принципиально иное решение: оно позволяет выполнять вычисления непосредственно над зашифрованными данными (шифротекстами), при этом результат расшифрования совпадает с результатом выполнения тех же операций над исходными открытыми данными. Как отмечается в современном обзоре, «Homomorphic Encryption (HE) enables secure computations on encrypted data without decryption, offering a transformative solution for privacy-preserving computation».

Идея вычислений над зашифрованными данными была впервые сформулирована в 1978 году Райвестом, Адлеманом и Дертузосом. Однако реализация полностью гомоморфного шифрования — схемы, поддерживающей произвольные вычисления неограниченной глубины, — оставалась неразрешимой задачей на протяжении трёх десятилетий. Прорыв произошёл в 2009 году, когда Крейг Гентри предложил первую конструкцию полностью гомоморфной криптосистемы. С этого момента началось активное развитие теории и практических реализаций FHE.

1. Математические основы гомоморфного шифрования

2.1 Формальное определение

Гомоморфная криптосистема с открытым ключом EE определяется четырьмя алгоритмами:

2. KeyGen - алгоритм генерации ключей, вырабатывающий секретный ключ s_k и открытый ключ p_k;

3. Encrypt — алгоритм шифрования: c = Encrypt (p_k, m), где m ∈ M — открытый текст, c ∈ C — шифротекст;

4. Decrypt — алгоритм расшифрования: m = Decrypt(s_k,c);

5. Evaluate – алгоритм вычисления: c_f = Evaluate(p_k, f, c_1, . . ., c_n), где f - функция, представимая в виде схемы из операций сложения и умножения.

Пусть M – множество открытых текстов с определёнными на нём операциями «+», «×», а C – множество шифротекстов с операциями $\oplus$, $\otimes$. Криптосистема называется гомоморфной относительно операций «+» и «×», если для любых m_1, m_2 ∈ M выполняются соотношения:

$Decrypt\ (s_k, Encrypt\ (p_k, m_1) \oplus Encrypt\ (p_k, m_2)) = m_1 + m_2,$

$Decrypt\ (s_k, Encrypt\ (p_k, m_1) \otimes Encrypt\ (p_k, m_2)) = m_1 \times m_2.$

В более общем виде гомоморфное шифрование требует выполнения двух условий: условия корректности (результат вычислений над шифротекстами после расшифрования совпадает с результатом вычислений над открытыми текстами) и условия конфиденциальности (промежуточные данные в процессе вычислений не раскрывают информации об открытых текстах).

2.2 Теоретико-кольцевая основа современных схем

Современные полностью гомоморфные схемы строятся на основе арифметики циклотомических колец. Кольцо имеет вид:

$R=Z[X]/(\Phi_m(X)),$

Где $\Phi_m(X)$ – m-й циклотомический многочлен. Для заданного модуля

q > 0 рассматривается фактор-кольцо R_q = R/qR.

Пространство открытых текстов в схеме BGV определяется как R_t = Z[X]/(Φ_n(X),t), где t - модуль открытого текста-. Шифротексты являются элементами кольца R_q, причём в процессе гомоморфных вычислений используются цепочки модулей {q_0, q_1, . . ., q_L} для управления уровнем шума.

2.3. Вычислительная задача Learning with Errors (LWE)

Основой безопасности подавляющего большинства современных FHE -схем является вычислительная задача Learning with Errors (LWE), предложенная Регевым в 2005 году.

Определение (Search LWE). Пусть заданы параметры n ∈ N, модуль q ≥ 2 и распределение ошибок χ на Z. Секретный вектор s ∈ Z выбирается равномерно случайно. Распределение LWE AS, χ

получается выбором a ← Z равномерно случайно, e ← χ и выдачей пары (a, ⟨ a, s ⟩ + e mod q). Задача Search LWE состоит в нахождении s по заданному набору независимых выборок из AS, χ.

Задача обучения с ошибками (*LWE*) заключается в нахождении вектора $s \in Z^m$ q-арной решетки L_q (все вычисления производятся по модулю q) при известной малой ошибке e. При этом $t = A \cdot s + e$, где A – матрица, столбцы которой представляют базис решетки (рис. 1). Если вектор ошибок e неизвестен, то найти $t = A \cdot s + e$ становится очень сложной задачей. Здесь s выполняет роль закрытого ключа, A, t – открытые ключи, e – закрытый случайный параметр

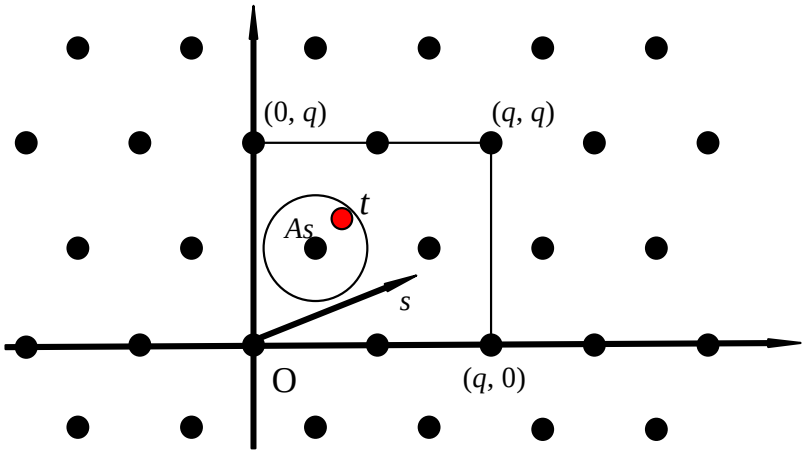

Рисунок 1 – Решение задачи *LWE* на алгебраической решетке

Ключевые свойства LWE, делающие её привлекательной для построения FHE:

1. Устойчивость к квантовым атакам;
2. Отсутствие известных субэкспоненциальных алгоритмов решения;
3. Сводимость к worst-case задачам на решётках;
4. Устойчивость к утечкам информации.

Ring-LWE (RLWE) является более эффективной версией LWE, в которой операции выполняются над элементами циклотомического кольца, что позволяет значительно сократить размер ключей и ускорить вычисления. Большинство современных FHE-схем (BGV, BFV, CKKS) базируются именно на RLWE.

3. Классификация схем гомоморфного шифрования:

3.1 Частично гомоморфное шифрование (Partially Homomorphic Encryption, PHE)

Схемы PHE поддерживают неограниченное количество операций только одного типа — либо сложения, либо умножения. Классические примеры:

- RSA - мультипликативно гомоморфен: $Enc(m_1) \cdot Enc(m_2) = Enc(m_1 \cdot m_2)$;
- Paillier – аддитивно гомоморфен: $Enc(m_1) \cdot Enc(m_2) = Enc(m_1 + m_2)$;
- Goldwasser-Micali — гомоморфен по операции XOR.

3.2 Полностью гомоморфное шифрование (Fully Homomorphic Encryption, FHE)

FHE-схемы поддерживают произвольные вычисления неограниченной глубины, представимые в виде схем из операций сложения и умножения. Именно FHE считается «святым Граалем» криптографии, поскольку она позволяет выполнять любые вычислимые функции над зашифрованными данным.

4. Эволюция полностью гомоморфных схем

4.1 Первая конструкция Гентри (2009)

Крейг Гентри предложил первую реализацию FHE, основанную на следующей двухэтапной стратегии:

1. Построение схемы SHE (somewhat homomorphic encryption), способной выполнять ограниченное число операций;

2. Применение бутстрапинга (bootstrapping) для преобразования SHE в FHE.

Бутстрапинг — ключевая инновация Гентри. Идея заключается в гомоморфном вычислении функции расшифрования: имея зашумлённый шифротекст и зашифрованный секретный ключ, схема вычисляет Decrypt (s_k, c) гомоморфно, получая «свежий» шифротекст Enc(m) с уменьшенным уровнем шума.

Теорема о бутстрапинге утверждает: если SHE-схема способна гомоморфно вычислить свою собственную функцию расшифрования (такая схема называется бутстрапируемой), то она может быть преобразована в FHE-схему.

4.2Технологические направления развития FHE

1. Современные FHE-схемы принято разделять на четыре технических направления на основе базовых криптографических примитивов:

2. Схемы на основе LWE/RLWE с использованием техники переключения модулей (modulus switching) и переключения ключей (key switching) — BGV, BFV;

3. Схемы на основе GSW (Gentry-Sahai-Waterman) с мультипликативным подходом к гомоморфным операциям;

4. Схемы на основе AP (Alperin-Sheriff-Peikert) с использованием функционального бутстрапинга — FHEW, TFHE;

5. Приближённые схемы (Approximate HE) — CKKS.

4.3Современные FHE – схемы

1. BGV (2011) — влиятельная схема на RLWE, вводит переключение модулей для снижения шума и поддерживает SIMD-упаковку нескольких текстов в один шифротекст.

2. BFV (2012) — аналогична BGV, но использует масштабирование открытых текстов для управления шумом; обеспечивает точные целочисленные вычисления и поддерживается библиотекой Microsoft SEAL.

3. CKKS (2017) — поддерживает приближённые вычисления над вещественными и комплексными числами, кодируя их в полиномы; допускает малую ошибку округления, что оптимально для машинного обучения и научных расчётов.

4. TFHE — работает над тором, обеспечивает быстрое выполнение булевых операций и функционального бутстрапинга, эффективна для битовых строк и малых целых чисел.

5. Современные вызовы и направления исследований

5.1. Вычислительная эффективность

Несмотря на значительный прогресс, FHE остаётся вычислительно затратной. Как отмечается в обзоре, «the application of FHE is constrained by its substantial computing overhead and storage cost». Основные направления ускорения включают:

1. Алгоритмическую оптимизацию: совершенствование бутстрапинга, улучшение управления шумом, использование техник упаковки данных;

2. Аппаратное ускорение: применение GPU, FPGA и специализированных ASIC для операций в кольцах;

3. Оптимизацию библиотек: Microsoft SEAL, HElib, PALISADE, OpenFHE, Lattigo.

5.2. Постквантовая безопасность

FHE-схемы на основе LWE и RLWE считаются устойчивыми к квантовым атакам, что делает их перспективными для постквантовой эпохи. Как подчёркивается в литературе, «HE's reliance on lattice-based problems like Learning With Errors (LWE) and Ring-LWE (...) provide quantum resistance».

5.3. Безопасность против атак с адаптивным выбором шифротекста (CCA2)

Фундаментальная теоретическая проблема FHE заключается в том, что гомоморфные схемы по определению являются маллеабельными (изменяемыми) — злоумышленник может модифицировать шифротекст с предсказуемым эффектом на открытый текст. Это делает FHE-схемы нестойкими против атак с адаптивным выбором шифротекста (CCA2). Поиск конструкций FHE, обеспечивающих CCA2-безопасность, остаётся открытой исследовательской задачей.

6. Прикладные аспекты

- Гомоморфное шифрование находит всё более широкое применение в различных областях:
- Облачные вычисления. HE позволяет делегировать обработку конфиденциальных данных облачным провайдерам без раскрытия самих данных. Облачный сервер выполняет вычисления над шифротекстами и возвращает зашифрованный результат, который может расшифровать только владелец данных.
- Машинное обучение с сохранением приватности (PPML). HE обеспечивает конфиденциальность обучающих данных и параметров моделей в процессах обучения и вывода. В обзоре рассмотрена интеграция HE с методами K-ближайших соседей (KNN), кластеризации K-средних и распознавания лиц.
- Медицина и геномика. HE позволяет проводить анализ геномных данных и медицинских записей без раскрытия конфиденциальной информации пациентов.
- Финансовая аналитика. HE обеспечивает конфиденциальность финансовых транзакций при проведении аналитических вычислений.
- Электронное голосование. Гомоморфные свойства Paillier и других схем используются для подсчёта голосов без раскрытия индивидуальных волеизъявлений.

7. Заключение

Гомоморфное шифрование прошло путь от теоретической концепции, впервые сформулированной в 1978 году, до практически реализуемых криптографических систем. Прорыв Гентри в 2009 году открыл эру полностью гомоморфного шифрования, а последующее десятилетие стало периодом интенсивного развития: появились схемы BGV, BFV, CKKS, TFHE, были созданы высокопроизводительные библиотеки (SEAL, HElib, OpenFHE), разработаны методы аппаратного ускорения.

Математической основой современных FHE-схем служат задачи LWE и RLWE на решётках, обеспечивающие постквантовую безопасность. Ключевыми техническими механизмами являются бутстрапинг, переключение модулей, переключение ключей и упаковка данных.

Несмотря на впечатляющий прогресс, остаются нерешёнными проблемы вычислительной эффективности, управления шумом и CCA2-безопасности. Однако, как справедливо отмечается в обзоре, «*HE's maturation from a theoretical concept to a practical solution demonstrates its potential as a cornerstone for secure, privacy-preserving computing across industries*». Дальнейшее развитие алгоритмических методов и аппаратных средств ускорения открывает перспективы широкого внедрения гомоморфного шифрования в облачные сервисы, системы искусственного интеллекта и критическую информационную инфраструктуру.

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AGRONOMY: FOUNDATIONS OF SUSTAINABLE CROP PRODUCTION AND FOOD SECURITY

Abstract

Agronomy constitutes the core scientific framework driving global crop production, soil management, and agricultural sustainability. As climate volatility increases and the global population expands, the field of agronomy must balance intensive yield production with environmental conservation. This article examines the contemporary paradigm of agronomic sciences, focusing on the critical relationship between soil health and crop optimization. It discusses the integration of innovative management strategies, resource conservation practices, and technological advancements designed to enhance food security. By synthesizing traditional cultivation methodologies with modern ecological insights, this study emphasizes the necessity of advanced agronomic practices in preserving finite natural resources while securing the global food supply chain.

Keywords:

Agronomy, Soil Conservation, Crop Yield, Sustainable Agriculture, Resource Management.

Main Part

Agronomy operates as a multi-disciplinary science that translates biological, chemical, and physical principles into practical cultivation strategies. The primary focus of modern agronomic intervention revolves around optimizing the interactions among the plant, the soil matrix, and prevailing atmospheric conditions. Agronomists work to develop superior crop varieties, implement effective crop rotation sequences, and devise balanced fertilization strategies tailored to specific geographic ecosystems. By managing these variables, agronomic science directly influences agricultural efficiency, ensuring that plants utilize available solar energy, water, and soil nutrients at maximum capacity. This scientific oversight is vital for minimizing crop losses caused by weeds, destructive insect pests, and volatile weather patterns.

Beyond direct plant cultivation, soil conservation forms the fundamental cornerstone of responsible agronomic engineering. Soil is not merely a structural medium but a dynamic, living ecosystem that dictates the carrying capacity of agricultural land. Modern agronomy addresses the threats of soil erosion, nutrient depletion, and salinization through targeted management frameworks. By applying conservation tillage techniques, establishing cover crops, and utilizing precise soil monitoring instruments, agronomists maintain soil organic matter and preserve complex microbial networks. These proactive interventions prevent the long-term degradation of arable lands, ensuring that agricultural soils retain their structural integrity, moisture-holding capacity, and biochemical fertility over successive generations of cultivation.

Technological Integration and Precision Agronomy

The field of agronomics has entered a highly transformative era marked by the extensive deployment of precision agriculture and digital resource mapping. Contemporary agronomists utilize satellite imagery,

global positioning systems, and automated weather stations to monitor crop fields with unmatched spatial accuracy. These digital tools analyze leaf area index, chlorophyll levels, and soil moisture variances across expansive agricultural zones, allowing for highly individualized field assessments.

Through the application of variable-rate technology, farmers can apply water, specific fertilizers, and targeted crop protection agents only where automated sensors indicate a statistical deficit. This precision approach eliminates the traditional practice of uniform field spraying, lowering input costs while reducing chemical runoff into surrounding ecosystems. The integration of data analytics into seasonal planning enables agronomists to accurately forecast harvest yields and dynamically adjust irrigation schedules to combat acute heat stress.

Climate Adaptation and Cropping System Resilience

As global temperature fluctuations shift historical growing seasons, agronomy plays a vital operational role in building climate-resilient farming systems. Agronomists work closely with plant breeders to evaluate drought-tolerant and heat-resistant crop varieties that thrive under reduced moisture conditions. Additionally, modern cultivation strategies emphasize diversifying crop patterns rather than relying on intensive monoculture systems.

Practices such as intercropping, conservation agriculture, and agroforestry are systematically utilized to enhance the ecological buffer of fields against extreme weather events. These diversified systems improve resource-use efficiency, naturally disrupt the reproductive cycles of common agricultural pests, and enhance structural biodiversity within the agricultural canopy. By adjusting sowing dates, utilizing innovative water-harvesting techniques, and selecting sturdy crop phenotypes, agronomists help stabilize regional food production lines despite shifting environmental climates.

Conclusion

Agronomy stands as an indispensable scientific discipline that bridges environmental conservation with international food production requirements. The continuous evolution of this field ensures that agricultural systems can elevate output metrics without causing irreversible ecological degradation. Through the successful combination of soil preservation strategies, climate-adaptive cropping systems, and data-driven precision technologies, agronomy provides the solutions needed to sustain a changing world. Continued capital investment in agronomic research, extension services, and educational infrastructure is essential to empower future practitioners to navigate the ecological and food security challenges of the coming decades.

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THE EVOLUTION OF VETERINARY MEDICINE: BALANCING ADVANCED DIAGNOSTICS WITH GLOBAL HEALTH SECURITY

Abstract

Veterinary medicine has evolved from an agriculture-focused livestock management practice into a complex, multifaceted scientific discipline critical to both animal welfare and human public health. This article explores the modern paradigm of veterinary sciences, highlighting the integration of advanced diagnostic technologies and the expanding role of veterinary professionals in managing zoonotic diseases—illnesses that spread between animals and humans. It examines the operational shifts in veterinary clinical practices and underscores the collaborative effort required to address global environmental and biological changes. Ultimately, this study demonstrates how contemporary veterinary medicine safeguards food production lines, domestic pet well-being, and broader ecological stability.

Keywords:

Veterinary Medicine, Zoonotic Disease, Diagnostic Imaging, Public Health, Animal Welfare.

Main Part

The scope of modern veterinary medicine extends far beyond the traditional care of domesticated animals, positioning itself as a cornerstone of global biosecurity and public health. In an interconnected world characterized by rapid urbanization and climate fluctuations, veterinarians serve as the primary line of defense against emerging infectious pathogens. Roughly 60 percent of all human infectious diseases originate in animals, and up to 75 percent of emerging diseases follow a zoonotic transmission pathway. By monitoring livestock populations, tracking wildlife health vectors, and managing domestic pet vaccination protocols, veterinary scientists actively intercept viral and bacterial threats before they cross the species barrier into human communities.

From a clinical diagnostic standpoint, the veterinary profession has experienced a massive technological transformation over the past two decades. The application of high-resolution magnetic resonance imaging, computed tomography scans, and rapid molecular polymerase chain reaction testing has mirrored advancements in human medicine. These sophisticated tools allow practitioners to diagnose complex oncological, orthopedic, and neurological conditions in non-verbal patients with unprecedented accuracy. Furthermore, the integration of targeted pharmacological therapies and minimally invasive surgical procedures has significantly extended the life expectancy and quality of life for companion animals, shifting the focus of veterinary clinics toward comprehensive long-term wellness and geriatric care.

Innovations in Livestock Management and Food Safety

Within the agricultural sector, veterinary medicine plays a vital role in ensuring global food safety and

the structural integrity of supply chains. Farm animal practitioners focus heavily on preventative herd health management, implementing strict biosecurity measures to shield production systems from devastating outbreaks such as avian influenza or African swine fever. By utilizing advanced herd monitoring software and automated health tracking sensors, veterinarians can isolate sick livestock early, minimizing the need for widespread medical interventions.

This proactive approach is closely tied to the international effort to regulate and reduce antimicrobial usage in food-producing animals. Modern livestock veterinary strategies emphasize the optimization of animal nutrition, pasture sanitation, and specialized immunization schedules to naturally boost herd immunity. These rigorous management frameworks directly protect consumers by preventing antibiotic residues from entering the food supply and reducing the selection pressure that drives the rise of drug-resistant bacterial strains.

The Growing Field of Veterinary Behavioral Science

Another significant development in contemporary animal care is the formal recognition and expansion of veterinary behavioral medicine. Understanding the psychological well-being of companion animals and captive wildlife has become an essential component of comprehensive veterinary assessments. Practitioners are increasingly trained to identify clinical anxiety, stress-induced disorders, and behavioral manifestations of chronic underlying physical pain that might otherwise go unnoticed.

This scientific shift has transformed standard veterinary hospital designs and handling protocols, introducing low-stress handling methods that reduce patient fear during clinical evaluations. By addressing behavioral health alongside physical symptoms, veterinarians help preserve the human-animal bond, reducing the number of companion animals abandoned or euthanized due to preventable behavioral conflicts. This holistic approach bridges the gap between basic animal physiology and emotional welfare.

Conclusion

Veterinary medicine stands today as a highly sophisticated, indispensable branch of the biological sciences. The field continues to adapt rapidly, utilizing cutting-edge diagnostic equipment to treat companion animals while simultaneously operating as a shield for global human health against zoonotic threats. As environmental pressures and global trade accelerate the interface between human populations, livestock, and wildlife, the expertise of veterinary professionals will remain essential. Continued investment in veterinary research, structural education, and diagnostic infrastructure ensures that this vital science can successfully meet the ecological and medical challenges of the future.

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THE INTERSECTING ROLES OF VETERINARY MEDICINE AND AGRICULTURE IN GLOBAL FOOD SECURITY

Abstract

The intersection of veterinary medicine and agriculture forms the foundation of sustainable food production systems and rural economic stability worldwide. As global populations rise, the agricultural sector faces pressure to increase output while minimizing environmental degradation and biological hazards. This article examines the collaborative relationship between veterinary sciences and modern farming, detailing how herd health management directly influences agricultural yields and economic outcomes. It analyzes the role of preventative medicine in controlling diseases within livestock populations, discusses technological advancements in livestock tracking, and reviews agricultural biosecurity strategies. Ultimately, this paper highlights how integrating veterinary expertise into agricultural practices ensures food safety, protects livestock welfare, and secures the human food supply.

Keywords:

Veterinary Agriculture, Livestock Productivity, Herd Management, Food Production, Biosecurity Measures.

Main Part

The historical and functional relationship between veterinary medicine and agriculture is rooted in the shared goal of maintaining healthy, productive livestock systems. Agriculture relies heavily on the constant availability of food-producing animals—such as cattle, sheep, poultry, and swine—to fulfill global demands for protein, dairy, and essential raw materials. Veterinary practitioners operating within this agricultural framework act as vital guardians of herd health, designing comprehensive vaccination schedules, managing reproductive cycles, and optimizing nutritional intake. When veterinary interventions successfully mitigate animal morbidity, agricultural operations experience improved feed-conversion efficiency, higher reproduction rates, and vastly superior product quality. Consequently, the financial viability of rural farming communities rests directly on the clinical expertise and preventative measures delivered by rural veterinarians.

Beyond immediate farm productivity, the integration of veterinary medicine into agricultural systems serves as the primary shield protecting the human food supply from contamination and pathogens. Food safety begins long before processing facilities, originating at the primary production level on the farm. Veterinarians systematically monitor livestock for systemic infections and metabolic conditions, ensuring that only healthy animals enter the processing pipeline. Furthermore, veterinary professionals manage the strict withdrawal periods required after administering therapeutic medications to livestock, preventing chemical and antibiotic residues from entering consumer markets. Through routine diagnostic testing, milk quality tracking, and biological monitoring on farms, agricultural veterinarians maintain the high standards necessary to uphold public confidence in national food networks.

Precision Agriculture and Veterinary Technology

Modern agricultural practices are increasingly adopting technological innovations, giving rise to

precision livestock farming. This movement blends data science with veterinary observation, using wearable biometric sensors, automated cameras, and electronic identification tags to monitor farm animals in real time. These digital tools continuously track individual animal behavioral patterns, shifts in body temperature, rumination dynamics, and feeding durations.

By analyzing this automated data streams, veterinary practitioners and farm managers can identify the earliest signs of subclinical illness days before physical indicators appear. This early detection capability allows for immediate isolation and targeted treatment of specific animals, significantly reducing the transmission velocity of infectious agents across large barns. The marriage of technology and clinical insight increases overall labor efficiency on commercial farms while elevating animal welfare standards through individualized attention.

Sustainable Livestock Production and Environmental Management

The current evolution of agricultural veterinary medicine places substantial emphasis on ecological sustainability and the reduction of the environmental footprint of farming. Ruminant livestock operations naturally generate greenhouse gas emissions, particularly methane, through enteric fermentation during digestion. Agricultural veterinarians collaborate with animal nutritionists to formulate specialized, highly digestible diets and feed additives that optimize the microflora within the animal's digestive tract.

These optimized feeding strategies not only lower enteric emissions per animal but also reduce nutrient excretion into the soil, protecting local waterways from nitrate and phosphorus runoff. Additionally, veterinarians advise producers on sustainable pasture rotation and manure management strategies that disrupt the life cycles of common parasites without relying excessively on chemical treatments. This holistic approach preserves chemical efficacy while supporting biodiversity within the agricultural ecosystem.

Conclusion

Veterinary medicine and agriculture remain fundamentally linked, acting as interdependent pillars that support global food production and rural economies. The continuous application of veterinary science to farming systems ensures that livestock populations remain healthy, resilient, and highly productive under varying environmental pressures. By embracing precision technology, strengthening on-farm biosecurity, and focusing on ecological sustainability, the agricultural sector can safely navigate the complex challenges of modern food production. Continued investment in veterinary-agricultural education and rural infrastructure is crucial to maintaining a secure, safe, and sustainable food supply for future generations.

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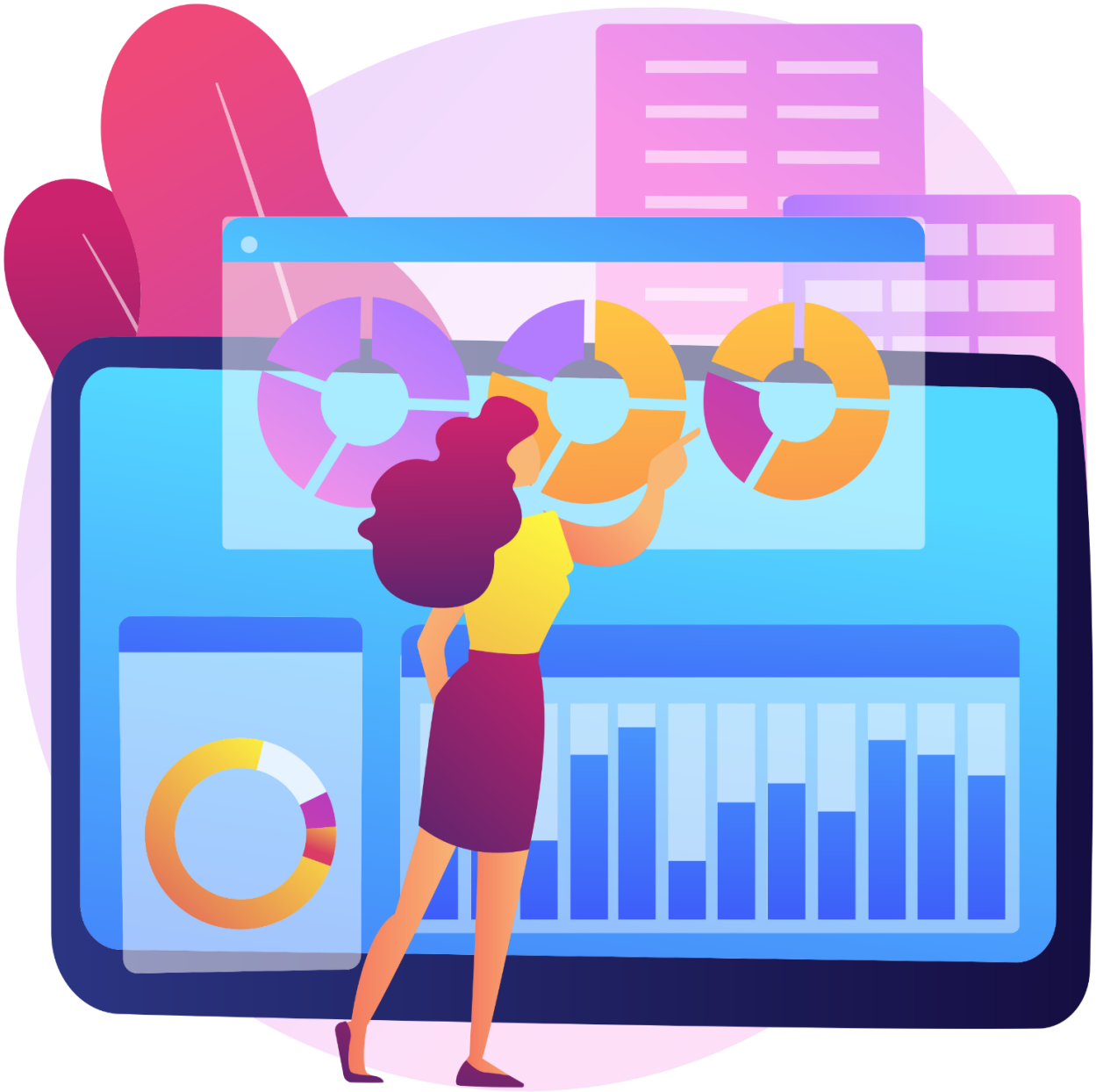

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AGRONOMY AND MODERN DEVELOPMENT: TRANSFORMING AGRICULTURE THROUGH SCIENTIFIC INNOVATION

Abstract

Agronomy serves as a primary engine for modern development, driving technological evolution, economic growth, and structural sustainability across global food systems. As societies modernize, the agricultural sector must transition from resource-intensive methodologies to knowledge-based, efficient frameworks. This article explores the relationship between advanced agronomic sciences and modern development paradigms. It examines how data-driven crop management, genetic innovations, and resource conservation techniques accelerate national development goals. By analyzing the integration of smart technologies and sustainable field practices, this study underscores the vital role that agronomy plays in securing urban food supplies, stabilizing rural economies, and preserving vital environmental resources for future generations.

Keywords:
Modern Development, Agronomic Innovation, Smart Agriculture,
Sustainable Yields, Technology Integration.

Main Part

The integration of agronomy into modern development frameworks marks a significant transition from traditional farming to highly technical, scientific resource management. Modern development is characterized by rapid urbanization, expanding industrial sectors, and an increasing reliance on digital infrastructure. To sustain this economic shift, the agricultural sector must produce larger volumes of high-quality raw materials and food products using less labor and fewer land resources. Agronomists address this challenge by developing high-yielding, stress-tolerant crop varieties and designing precise cultivation schedules that optimize plant growth. By transforming agriculture into a highly predictable and productive science, agronomy releases excess labor forces for industrial diversification while ensuring that urban populations have access to stable, affordable food networks.

Furthermore, national development strategies rely heavily on the capacity of modern agronomy to protect finite natural resources from irreversible degradation. Traditional development models often prioritized short-term agricultural output at the expense of long-term environmental health, resulting in widespread soil erosion, deforestation, and water scarcity. Contemporary agronomic science corrects this trajectory by embedding conservation engineering directly into modern farming routines. Through the deployment of zero-tillage systems, organic soil amendments, and biological crop protection frameworks, agronomists prevent the destruction of arable lands. This protective oversight ensures that industrial and economic expansion does not collapse the ecological foundations that support human society, aligning agricultural growth with international definitions of sustainable development.

Precision Infrastructure and Digital Development

A defining characteristic of modern development is the digital transformation of primary industries, a movement heavily visible in precision agronomy. Contemporary farming operations utilize internet-of-things sensors, satellite remote sensing, and automated machinery to manage expansive fields with extreme accuracy. Agronomists utilize these interconnected systems to map localized soil chemistry variances, track real-time crop health metrics, and monitor microclimatic shifts across diverse agricultural zones.

This wealth of digital information allows for the automated execution of variable-rate input applications, delivering specific quantities of water, nitrogen, and protective treatments only where computational models identify an explicit deficit. This precision approach eliminates the inefficient practice of uniform field spraying, drastically lowering operational costs for farming enterprises while protecting adjacent aquatic habitats from chemical pollution. The integration of data analytics into seasonal planning equips farm managers with the tools necessary to forecast harvest yields and dynamically adapt to sudden environmental changes.

Biotechnology and Crop System Resilience

Another major cornerstone of agronomy within modern development frameworks is the rapid advancement of agricultural biotechnology and molecular plant breeding. Traditional breeding techniques are being supplemented with precise genetic selection tools to develop crop phenotypes engineered for specific environmental stresses. Agronomists work to field-test and deploy crop varieties that exhibit high resistance to prolonged droughts, elevated soil salinity levels, and aggressive insect pests.

These biological innovations allow agricultural operations to expand safely into marginal or partially degraded lands, transforming underutilized regions into productive economic zones. Additionally, these resilient crop systems naturally lower the requirement for synthetic chemical inputs, reducing production hazards for farmworkers and minimizing chemical residues within the consumer food supply. By stabilizing production yields under adverse environmental conditions, biotechnology provides a reliable mechanism to protect national food security against global climate volatility.

Conclusion

Agronomy functions as an indispensable pillar of modern development, providing the scientific innovations required to balance industrial growth with environmental safety. By shifting the agricultural sector toward a data-driven, ecologically conscious model, agronomic science ensures that food production can meet the demands of a changing world. The successful scaling of precision technologies, conservation infrastructure, and resilient crop varieties demonstrates that economic advancement can coexist with natural resource preservation. To maintain this developmental velocity and secure global food networks, international institutions must prioritize continuous financial investments in public agronomic research, rural technical education, and modern agricultural extension services.

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THE INTERSECTION OF AGRONOMY AND ECOLOGY: PRINCIPLES OF SUSTAINABLE AGROECOSYSTEM MANAGEMENT

Abstract

The intersection of agronomy and ecology has given rise to agroecology, a critical scientific framework that views agricultural fields as complex, living ecosystems. As modern agricultural production faces the twin challenges of environmental degradation and rising global food demand, traditional high-input farming methods must transition toward ecologically sound practices. This article examines how ecological principles can be applied to agronomic systems to enhance biodiversity, optimize natural nutrient cycles, and minimize reliance on synthetic inputs. It analyzes the role of soil biodiversity in sustaining crop health, evaluates the ecological benefits of diversified cropping patterns, and explores natural pest management solutions. Ultimately, this study demonstrates that integrating ecological science into agronomy is essential for securing long-term food production while preserving global environmental stability.

Keywords:

Agroecology, Ecosystem Services, Biodiversity, Nutrient Cycling, Sustainable Agriculture.

Main Part

The integration of ecological principles into agronomic practices marks a significant shift from conventional, chemically intensive farming to sustainable resource management. Historically, industrialized agriculture focused primarily on maximizing crop yields through the heavy application of synthetic fertilizers and chemical pesticides, often ignoring the long-term ecological consequences. In contrast, the collaboration between agronomy and ecology treats the farm as a functional agroecosystem where biological components interact dynamically. Agronomists utilizing ecological strategies focus on maximizing internal biological processes rather than relying on external inputs. By understanding the relationships between plants, insects, soil organisms, and wildlife, modern agricultural systems can maintain high productivity while reducing environmental pollution, habitat destruction, and greenhouse gas emissions.

A central point of focus at the intersection of agronomy and ecology is the preservation and enhancement of soil biodiversity. Soil is not merely an inert anchor for plant roots; it is a complex ecological web populated by billions of bacteria, fungi, protozoa, and beneficial insects. Ecologically minded agronomic practices, such as minimal tillage and the application of organic compost, protect these soil communities from physical and chemical disruptions. These organisms drive essential ecosystem services, including the decomposition of organic matter, the natural fixation of nitrogen, and the stabilization of soil structures against wind and water erosion. By fostering a diverse and healthy soil microbiome, agronomists can naturally enhance crop resilience to droughts, reduce the prevalence of soil-borne plant pathogens, and

eliminate the need for excessive chemical fertilization.

Diversified Cropping Designs and Landscape Ecology

Modern agroecological management heavily emphasizes the transition away from extensive monoculture farming toward diversified cropping systems. Cultivating a single crop species over thousands of contiguous hectares simplifies the landscape, making the system highly vulnerable to catastrophic pest outbreaks and rapid nutrient depletion. Agronomists address this vulnerability by implementing ecological designs such as multi-species crop rotations, companion planting, and agroforestry networks.

These diversified designs mimic natural ecosystems by occupying distinct ecological niches, maximizing solar energy capture, and utilizing soil water layers more efficiently. Furthermore, integrating natural field borders, hedge rows, and flowering vegetative strips into the agricultural landscape supports regional wildlife conservation. These non-crop vegetation zones provide vital food sources and nesting habitats for native pollinators and migratory bird species, strengthening the ecological buffer of the surrounding environment.

Biological Pest Regulation and Ecological Control

Another major development within ecological agronomy is the application of biological pest regulation strategies to reduce chemical dependency. Conventional synthetic insecticides frequently eliminate non-target beneficial insects, leading to secondary pest outbreaks and the rise of chemical-resistant insect populations. Ecological pest management uses natural predator-prey dynamics to keep pest populations below damaging thresholds without entirely wiping out species.

By intentionally introducing or attracting natural predators—such as ladybugs, lacewings, parasitic wasps, and insectivorous birds—farmers can establish a self-regulating biological control system within the crop canopy. Agronomists also utilize trap crops, which are attractive plant species grown near the main crop to lure pests away from the primary economic harvest. This natural approach protects worker health, prevents toxic chemical runoff into local freshwater streams, and maintains the equilibrium of the local food chain.

Conclusion

The collaboration between agronomy and ecology provides a path forward for global food production that balances human nutritional requirements with environmental safety. By treating agricultural lands as dynamic ecosystems, agronomists can utilize natural biological processes to nourish crops, protect harvests, and regenerate degraded soils. The transition to ecologically managed farming systems is no longer an optional alternative but a structural necessity to combat global biodiversity loss and environmental pollution. Continued investment in agroecological research, rural extension programs, and sustainable policy frameworks is vital to ensure that modern farming operations can function in harmony with the natural world for generations to come.

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AGRONOMY AND ECONOMY: MAXIMIZING AGRICULTURAL EFFICIENCY AND MARKET VIABILITY

Abstract

The interaction between agronomy and economic science forms the basis of global food security, agricultural market stability, and rural development. While agronomy provides the biological and chemical methodologies required to optimize crop yields and preserve soil resources, economic principles dictate the financial viability and resource allocation within farming systems. This article explores the interconnected dynamics of agronomic management and agricultural economics, focusing on how data-driven crop production influences market behaviors and farm profitability. It analyzes the financial impacts of precision agriculture technologies, evaluates risk management strategies under volatile climate conditions, and discusses sustainable yield intensification from a cost-benefit perspective. Ultimately, this study demonstrates that pairing robust scientific cultivation with sound economic frameworks is essential for building resilient, profitable, and food-secure nations.

Keywords:

Agricultural Economics, Crop Efficiency, Resource Allocation, Farm Profitability, Market Viability.

Main Part

The relationship between agronomy and economy represents the direct translation of plant and soil sciences into financial returns and market value. Agriculture operates within a highly competitive global marketplace where farming enterprises must constantly balance production costs against fluctuating commodity prices. Agronomists act as essential economic facilitators by developing cultivation methodologies that lower input costs while simultaneously raising the volume and grade of the harvest. By optimizing sowing densities, prescribing exact fertilizer applications, and creating targeted pest management schedules, agronomic science minimizes resource waste. When farmers successfully reduce expenditures on synthetic inputs without sacrificing crop volume, the direct net profit margin of the agricultural enterprise increases, strengthening the broader regional economy.

Beyond individual farm management, national economic stability depends heavily on the systemic application of agronomic research to agricultural supply chains. Fluctuations in domestic crop yields can trigger severe macroeconomic shocks, including food price inflation, trade deficits, and supply chain disruptions. A highly sophisticated agronomic infrastructure provides the tools necessary to stabilize national crop production through shifting weather patterns and biological threats. By securing predictable harvest volumes, agronomy allows agricultural economists to formulate stable trade policies, secure international export markets, and plan accurate national food reserves. Consequently, structural investments in public agronomic research and extension networks yield high macroeconomic returns, preventing food shortages and fostering industrial growth within processing sectors.

Precision Capital Investment and Financial Returns

The modern evolution of agricultural management relies heavily on integrating precision agronomy

with financial technology to optimize capital expenditures. Commercial and smallholder operations are adopting precision instruments, such as variable-rate fertilizer spreaders, automated tractor guidance networks, and real-time remote crop sensors. These data-driven systems allow agronomists to treat variations within a single field individually, applying expensive inputs like nitrogen and water only where statistical deficits are detected.

From an economic perspective, this precise methodology shifts the cost structure of farming by drastically reducing variable input expenses. Although the initial capital investment required to acquire precision machinery can be substantial, long-term financial analysis demonstrates clear cost-saving advantages and accelerated returns on investment. The collection of digital field data also provides farm operators with precise production histories, which simplifies access to commercial bank loans, agricultural credit lines, and specialized crop insurance packages.

Risk Mitigation and Sustainable Financial Development

Another critical area at the intersection of agronomy and economy is the development of long-term risk mitigation strategies to combat climate and market volatility. Single-crop reliance, or intensive monoculture, exposes farmers to extreme financial hazards if a specific crop succumbs to targeted diseases or localized drought conditions. Agronomists address this economic vulnerability by designing diversified cropping systems, such as multi-year rotations, cover-cropping frameworks, and intercropping models.

These diversified systems distribute financial risk across multiple crop varieties, ensuring that a market price collapse or crop failure in one sector does not bankrupt the entire enterprise. Additionally, these biological systems naturally improve soil structure, enhance water retention, and reduce weed pressures over time. By utilizing natural ecological functions to maintain field health, farmers can systematically lower their dependence on expensive chemical interventions, building a low-input, economically resilient model that remains viable through shifting global climates.

Conclusion

Agronomy and economy function as interdependent pillars that guide modern food production and sustain global market networks. The strategic application of agronomic science ensures that agricultural systems remain highly productive, resource-efficient, and financially sound amid shifting environmental and trade realities. By expanding precision technologies, adopting diversified risk-mitigation strategies, and lowering dependency on costly synthetic inputs, the global agricultural sector can achieve both ecological sustainability and financial longevity. Sustained investment in agricultural economics, public agronomic education, and rural support frameworks remains vital to empower the next generation of food producers to build stable, profitable, and food-secure societies.

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ФИЛОЛОГИЯ

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APPLYING THE SHADOWING TECHNIQUE IN ENGLISH CLASSES AT HANOI UNIVERSITY OF MINING AND GEOLOGY

Abstract

This paper discusses the use of shadowing in English classes for non-English-major students at Hanoi University of Mining and Geology. Many students find listening and speaking difficult because they have limited chances to practise, cannot easily follow natural speech, and are not confident about pronunciation, stress, rhythm, and intonation. Shadowing is a technique in which learners listen to a recording and repeat the speaker with only a very short delay. When it is used with suitable materials and clear guidance, shadowing can help students recognize spoken English more easily, improve pronunciation, speak more smoothly, and become more confident. This paper explains the main benefits of shadowing and suggests a simple classroom procedure, including listening for meaning, studying the transcript, practising short phrases, shadowing the whole passage, recording, and self-checking. It also stresses that shadowing should be combined with discussion, summarizing, and other speaking activities so that students can use what they have practised in real communication.

Keywords:

English teaching; listening and speaking; shadowing; pronunciation; university students.

1. Introduction

English proficiency is crucial for technical students, making practical university courses essential for navigating professional materials and global communication. While listening and speaking remain challenging for non-majors, shadowing techniques—simultaneously listening and mimicking speech—can improve pronunciation and communication, provided that teachers select appropriate materials and foster communicative, meaning-focused practice.

2. Listening and Speaking Difficulties of HUMG Students

2.1. Common difficulties in listening and speaking

HUMG students span various majors with diverse English levels, facing limited individual practice in large classes. Speaking requires idea organization, interaction, and correct pronunciation, but fear of mistakes causes hesitation, leading students to read pre-written texts or give short responses due to low vocabulary. To boost participation, teachers should replace abstract or overly technical topics with familiar, career-related themes like safety, teamwork, and technology, bridging general English and major-specific English. Listening is similarly hindered by fast pacing, connected speech, and weak forms, causing students to lose the main idea and feel anxious. Poor classroom acoustics worsen this, highlighting the need for focused practice like shadowing to master natural spoken features like stress, linking, and intonation.

2.2. Pronunciation, stress, and intonation

English and Vietnamese utilize sound and pitch differently; Vietnamese is tonal, whereas English relies on stress, rhythm, and intonation, causing Vietnamese learners to often speak with equal stress or excessive pauses, reducing naturalness and intelligibility (Nguyễn Huy Kỷ, 2010). Additionally, navigating various English accents can confuse beginners, so instead of demanding accent perfection, teachers should aim for clarity and comprehension by starting with one clear model before introducing diverse accents. In this context, shadowing serves as a useful technique to help students notice how different speakers organize sounds, stress, and rhythm.

3. The Shadowing Technique and Its Benefits

3.1. What is shadowing?

The word shadowing comes from a shadow following a person closely, where learners listen to a recording and repeat the speech after a very short delay, mirroring the speaker's words, speed, stress, rhythm, pauses, and intonation (Lambert, 1992). Unlike normal repetition where students wait for a sentence to end, or reading aloud which relies heavily on text, shadowing requires students to speak while the audio continues and gradually depend more on listening. Because managing listening, retention, and speaking simultaneously is demanding, teachers should begin with short, clear recordings, ensuring students understand the topic and vocabulary through a gradual procedure suitable for lower-level learners.

3.2. Main benefits of shadowing

Shadowing enhances listening as students closely track sounds to recognize linking, weak forms, and reduced speech features. It also improves pronunciation by letting students compare their speech against a clear model to correct final consonants, word stress, and intonation, showing positive outcomes for non-majors (Lê Thị Thu Huyền, 2021). Furthermore, repeating useful phrases develops fluency, reducing pauses and native-language translation, though it must be paired with active discussions for free speaking. Additionally, because content is provided, shadowing builds confidence and lowers anxiety for shy students who can track their progress through personal voice recordings. Finally, the technique is ideal for self-study using phones or computers to slow down audio, view subtitles, and record voices outside class.

3.3. Why shadowing is suitable for HUMG students

Shadowing adapts well to different proficiency levels and HUMG majors, allowing beginners to use short everyday conversations while advanced students practice with technical materials like interviews or presentations on technology, geology, and energy to support both general and specific English purposes. The technique is also highly practical in large classes because students can practice individually with earphones, work in pairs, or collaborate in small groups within five to ten minutes of a regular lesson. However, shadowing is not a complete solution, as it does not automatically teach students how to take turns, ask questions, or respond naturally; therefore, it is most useful when integrated into a wider lesson that includes listening for meaning and real communication.

4. Practical Suggestions for Using Shadowing

4.1. Choosing suitable materials

Teachers should begin with clear, familiar recordings of twenty to sixty seconds that include transcripts, ensuring the speed, vocabulary, sentence length, and background noise match students' levels. To keep the focus on listening and speaking, teachers can explain key vocabulary beforehand, avoiding materials that are too far above the students' current proficiency. Content should be engaging and practical, utilizing resources like coursebook audio, short educational videos, TED clips, BBC Learning English, or major-specific topics for HUMG students such as mining safety, renewable energy, and workplace communication. Initially, students must work with a clear, consistent model, but teachers can later introduce diverse accents and speaking styles to help them develop into flexible listeners.

4.2. A simple classroom procedure

The following six steps make shadowing easier and more useful. In Step 1, students listen once or twice without speaking to identify the topic, speaker, and main idea, with the teacher checking understanding via simple questions. In Step 2, students study the transcript, verify vocabulary, and listen again to mark stressed words, pauses, linking, and intonation changes. In Step 3, the recording is divided into short phrases so students can listen, pause, and repeat while focusing on clear sounds, final consonants, and word stress. In Step 4, students speak along with the audio while reading the transcript, gradually looking only at key words or covering sections to listen more carefully. In Step 5, students shadow the whole passage at normal speed without restarting after small mistakes, aiming to maintain the overall rhythm and main phrases. Finally, in

Step 6, students record their final attempt, compare it with the model, and select one or two specific areas for improvement, such as speed or final sounds.

4.3. Organizing practice and giving feedback

In a large class, students can work in pairs or small groups where one student shadows while a partner listens with a short checklist, swapping roles afterward so the teacher can circulate and address key problems. To maintain confidence, peer feedback must be respectful, and teachers should focus on major comprehensibility issues—such as missing final sounds, incorrect word stress, equal emphasis, or excessive pauses—rather than correcting every sound. Teachers can demonstrate a short phrase and use hand movements to show stress before asking students to try again. Finally, students should follow up with a communicative speaking task using the recording's content, such as summarizing, answering questions, retelling information, discussing the topic, or giving a short presentation. For technical topics, they can explain a process in simpler English or connect the information to their own major, helping them transition from imitation to authentic language use.

4.4. Practice time and self-study

Teachers should increase difficulty slowly by avoiding raising the topic complexity, vocabulary density, accent variety, and speed all at once. During preparation, students can temporarily slow down recordings but must gradually return to normal speed. Short, regular practice—such as five to ten minutes in class or fifteen to twenty minutes several times a week for self-study—is more effective than infrequent, long sessions, especially when paired with a clear focal goal like final consonants or sentence stress. Digital tools like playback-speed control, subtitles, online dictionaries, and voice recording support independent practice, though automatic speech-recognition scores should be treated as guides rather than absolute measures. Finally, a simple assessment focusing on listening accuracy, clarity, rhythm, and continuity should compare a student's initial and later recordings to measure individual progress rather than comparing them directly with a native speaker.

Table 1

Simple criteria for checking shadowing practice

Area	What to check	Main feedback
Listening accuracy	Missing or changing words; ability to follow the recording	Follow key words and phrases
Clear pronunciation	Sounds, final consonants, and word stress	Correct problems that affect understanding
Rhythm and phrasing	Sentence stress, linking, pauses, and intonation	Do not stress every word equally
Continuity	Speed, hesitation, and ability to continue after a mistake	Keep going instead of restarting often

5. Conclusion

Shadowing is a useful technique for improving listening and speaking when used in a clear, gradual way, helping students hear connected speech, practice pronunciation, follow English rhythm, and speak with greater confidence, especially for those with limited language opportunities outside the classroom. For HUMG students, shadowing adapts to both general English and major-related materials, where success relies on choosing suitable recordings, ensuring comprehension, practicing in small steps, and providing simple feedback to achieve the main aim of clearer communication rather than native-speaker perfection. Ultimately, shadowing should always be followed by communicative activities like summarizing, explaining, discussing, or asking questions, serving as a practical bridge between listening practice and real language use.

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ПЕДАГОГИКА

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APPLYING PAIR WORK AND GROUP WORK IN FOREIGN LANGUAGE CLASSROOMS TO IMPROVE STUDENTS' SPEAKING SKILLS

Abstract

Pair work and group work are widely used classroom organizational techniques in communicative language teaching. This paper analyzes the role of pair work and group work in developing students' English-speaking skills, while also presenting their advantages, key principles for effective implementation, and several approaches to organizing pairs and groups to enhance classroom effectiveness. Drawing on practical teaching experience, the paper argues that the appropriate use of pair work and group work not only increases students' opportunities to practice speaking and promotes active learner participation, but also enhances their communicative competence, collaborative skills, and self-confidence throughout the process of learning English.

Keywords:

pair work; group work; speaking skills; foreign language teaching; communication; university students.

1. Introduction

In the era of international integration, English proficiency—especially speaking skills—is a crucial advantage in the labor market, enabling graduates to communicate effectively and enhance their competitiveness. However, many university students still lack the confidence and competence to communicate in English after years of study, failing to meet employers' expectations. As an English lecturer, I have continually sought effective classroom approaches to maximize speaking practice, where pair work and group work are widely recognized as powerful techniques that promote interaction, encourage authentic communication, and naturally develop speaking skills. Therefore, this paper discusses the benefits of pair and group work and presents practical strategies for organizing these activities to improve students' English-speaking skills.

2. Content

Pair work and group work are widely used teaching techniques that develop students' speaking skills by encouraging active participation, fostering learner autonomy, and reducing dependence on the teacher. Working in pairs or small groups provides students with more opportunities to exchange ideas, collaborate on tasks, and practice English in authentic communicative situations. When properly organized, these techniques create an engaging, interactive learning environment that involves all students and enhances speaking practice, while the lecturer acts as a facilitator, guide, and supporter to monitor the process and assist students with any difficulties.

2.1. The Concept of Pair Work and Group Work

Pair work and group work are learner-centered techniques widely used in language teaching to increase practice opportunities, with pair work involving two learners and group work involving several collaborating via discussion (Harmer, 2007). According to Richards and Rodgers (2014), both are essential components of Communicative Language Teaching (CLT) as they mirror real-life communication, allowing students to actively exchange ideas, negotiate meaning, and interact rather than passively receiving knowledge. In English language teaching, these techniques are commonly applied in speaking activities like role-plays, discussions, debates, interviews, and small projects, helping students develop not only communicative competence but also teamwork, critical thinking, and autonomous learning abilities.

2.2. Advantages of Pair Work and Group Work

Pair work and group work, involving students working simultaneously in pairs or small groups of four to five, are widely used techniques that maximize classroom interaction and active participation. These methods significantly increase individual speaking practice and reduce stress, especially for shy students, compared to traditional whole-class formats. Consequently, communicating within smaller groups lowers anxiety about making mistakes, boosting students' confidence to express opinions and use English naturally. Furthermore, these activities transform the teacher into a facilitator, organizer, and guide, establishing a learner-centered environment that encourages greater student responsibility. Finally, collaborative interaction fosters peer learning and mutual support, allowing students to share knowledge, correct errors, and enhance their teamwork, autonomy, and communicative competence.

2.3. Considerations for Organizing Pair Work and Group Work

Pair work and group work are effective learner-centered techniques, yet their success depends heavily on teacher organization and classroom management through four key considerations. First, teachers must carefully prepare tasks appropriate to lesson objectives and student levels, providing guiding questions, key vocabulary, or language models to keep discussions on-topic and meaningful. Second, clear, brief instructions regarding objectives, procedures, and time limits must be given before the activity starts, ideally accompanied by teacher-student demonstrations to eliminate confusion. Third, during the activity, teachers should move around the room to monitor progress, encourage equal participation from all members, and offer timely support without intervening excessively. Fourth, post-activity reporting and evaluation are essential; teachers should randomly select groups to present, encourage peer feedback, and provide constructive summaries focusing on progress, strengths, and language reinforcement. In conclusion, effective collaborative learning requires systematic planning, execution, and evaluation to transform the classroom into a natural communicative environment that enhances students' language competence and teamwork skills.

2.4. Ways of Organizing Pairs and Groups

The way pairs and groups are formed directly impacts learning effectiveness, where appropriate grouping maximizes interaction and inappropriate grouping hinders participation. Depending on objectives and context, teachers can adopt three main strategies. First, grouping students with friends makes them feel comfortable and confident, which is ideal for large classes, though overusing it limits interaction with other peers. Second, grouping by proficiency levels can either pair stronger students with weaker ones to encourage peer tutoring, or cluster similar levels together to allow teachers to assign differentiated, targeted tasks. Third, random grouping—using seating, numbers, or cards—adds variety, allows students to collaborate with different partners, and maintains a fresh classroom dynamic. Ultimately, teachers must remain flexible, combining these strategies to suit class size and individual learner characteristics, as varying grouping methods maintains motivation and helps students develop broad communication and adaptability skills.

2.5. Some Pair and Group Activities for Speaking Classes

Teachers can employ a variety of pair and group activities to provide students with meaningful speaking practice. For instance, in role-plays, students take on different roles like customer and assistant or interviewer and applicant, while information-gap activities require them to exchange missing information to complete a task. Additionally, group discussions allow students to debate topics like environmental protection or artificial intelligence, whereas problem-solving tasks challenge groups to find solutions to real-life situations. Finally, picture descriptions encourage pairs to describe and compare images, and mini-debates prompt two groups to defend opposing viewpoints on an issue. Collectively, these activities create authentic communicative environments where students can apply their vocabulary, grammatical knowledge, and speaking skills in realistic contexts.

2.6. Some Challenges in Organizing Pair Work and Group Work

Although pair work and group work offer numerous benefits, their implementation presents several challenges, particularly in large classes where monitoring all groups simultaneously is difficult and students often revert to their native language. Additionally, uneven language proficiency can cause active students to dominate while less proficient ones contribute little or rely heavily on peers. Managing class time, controlling noise, and fairly assessing individual contributions also demand significant teacher effort. Therefore, teachers must carefully prepare tasks, establish clear assessment criteria, and regularly vary group formations to ensure equal and active participation from all students.

3. Conclusion

Pair work and group work are learner-centered instructional strategies that encourage active participation, giving students more opportunities to practice speaking English than traditional teacher-centered classrooms, thereby improving communicative competence and real-life language application. Notably, shy or less confident students gain a supportive, low-pressure environment to practice freely, gradually building confidence and fluency. Furthermore, implementing these activities transforms the teacher's role from a knowledge transmitter to a facilitator, organizer, and supporter responsible for designing meaningful tasks, monitoring interactions, guiding when necessary, and providing vocabulary or language support. In conclusion, when carefully planned and aligned with lesson objectives and student proficiency, pair and group work significantly enhance English speaking instruction, and it is hoped that these collaborative strategies will be widely adopted to improve communicative competence, particularly among students at Hanoi University of Mining and Geology.

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INTEGRATING LOCAL CULTURE INTO TEACHING ENGLISH AS AN INTERNATIONAL LANGUAGE: AN EXAMPLE FROM HANOI UNIVERSITY OF MINING AND GEOLOGY

Abstract

The shift from a native-speaker model toward English as an International Language (EIL) emphasizes intercultural communication and enables learners to express their own cultural identities. This paper reviews EIL principles and demonstrates their application by adapting a reading lesson from New English File (Pre-Intermediate) for Hanoi University of Mining and Geology (HUMG) students. By replacing unfamiliar Western

cultural content with profiles of two popular Vietnamese singers, Trần Lập and Sơn Tùng M-TP, and incorporating communicative pair-work, the redesigned lesson connected classroom activities with students' personal experiences and cultural knowledge. This adapted approach fostered a more engaging environment, noticeably increasing learner motivation, confidence, and active participation in speaking tasks. Ultimately, the study demonstrates that integrating local culture aligns with the EIL principle of "Think globally, but act locally," enhancing communicative competence while preserving cultural identity and highlighting the vital role of teacher adaptation in language instruction.

Keywords:

English as an International Language (EIL); Teaching English as an International Language (TEIL); material adaptation; local culture; communicative language teaching; intercultural communication.

1. Introduction

Nowadays, English dominates international communication, playing a crucial role in business, technology, science, education, and diplomacy (Roux, 2014). Globalization makes English proficiency essential for academic success, professional development, and cross-cultural communication, with Crystal (1997) noting that English is used in 85% of major films, 90% of scientific publications, and 90% of Asian international organizations. Given this importance, English teaching must focus on linguistic competence while preparing learners for diverse intercultural contexts. This report presents an experience of adapting teaching materials for Hanoi University of Mining and Geology (HUMG) students to support English as an International Language (EIL), developing their language skills, intercultural awareness, and communicative competence to become active global citizens.

2. Contents

2.1. What Is an International Language?

An international language is not defined by its native-speaking population; otherwise, Mandarin Chinese, Spanish, Arabic, or Hindi would share that status, yet they do not function as global means of communication. Smith (1976) defined an international language as one used by people of different nations to communicate with one another, emphasizing its communicative role across national and linguistic boundaries. Similarly, McKay (2002) argued that international status depends on geographical distribution and widespread use by non-native speakers. Thus, a language becomes international by serving as a common medium of communication among people from diverse linguistic and cultural backgrounds, explaining why English has achieved its global recognition today.

2.2. The Spread of English as an International Language

The rapid spread of English has made it the world's primary international language, with Michael and Fazard (2008) estimating 380 million native speakers and over one billion second or foreign language users, demonstrating an influence far beyond mother-tongue nations (Crystal, 1997). Driven by globalization, English serves as a common medium for international business, science, education, diplomacy, and media, meaning people learn it to interact with both native and non-native speakers. McKay (2002) notes that English operates in both a global sense, facilitating communication across borders, and a local sense, functioning within multilingual societies for education and business. Furthermore, Crystal (1997) asserts that this international status is achieved either by adopting English as an official language in administration and education or by widely teaching it as a foreign language for its practical value in employment, higher education, and technological access.

2.3. Features of English as an International Language

An international language enables communication among diverse linguistic backgrounds and, as Smith (1976) notes, is not tied to any single nation but serves as a cross-country medium. Consequently, EIL relies

on three assumptions: learners need not adopt native cultural norms and can maintain their own identity; the educational goal is effective communication of personal values rather than native imitation; and ownership is de-nationalized, belonging to all global users. Expanding this, Brutt-Griffler (2002) identifies key global characteristics: EIL stems from a growing global ethnocultural system across trade, science, and intellect; it coexists with rather than replaces local languages, functioning as an additional tool; and its spread occurs via intentional language learning rather than native speaker migration. Together, these elements prove English is a shared global resource that facilitates intercultural communication while preserving users' distinct cultural identities.

2.4. An Example of Applying Teaching English as an International Language

According to Smith (1976), the educational goal of learning an international language is to enable learners to communicate their own ideas and culture to others. Based on this perspective, I adapted a reading and speaking lesson from Unit 7B – Born to Direct (p. 78) of New English File (Pre-Intermediate) to better suit the cultural background of my students. In the original textbook, students read about Western film directors Alfred Hitchcock and Quentin Tarantino; however, past teaching experience showed that students struggled to relate to these foreign figures, leading to low interest and reduced speaking effectiveness. To make the lesson more meaningful, I replaced these directors with two famous Vietnamese singers, Trần Lập and Sơn Tùng M-TP, who are highly familiar to local students. This adaptation aligns with the principles of Teaching English as an International Language (TEIL) by allowing learners to express their own cultural identities rather than focusing solely on native-speaker cultures. Furthermore, I redesigned the lesson to emphasize pair work, requiring students to collaborate, ask questions, compare the singers, and share opinions. These communicative activities provided meaningful speaking practice on familiar topics, noticeably boosting student motivation, confidence, and classroom interaction. Ultimately, this approach illustrates how localizing materials and embedding collaborative tasks can fulfill the EIL goal of using English as a tool to share one's culture.

1. He was born on **12 December 1974**.
2. He was born on **5 July 1994**.
3. He was a **Vietnamese rock musician and singer**.
4. When he was **two years old**, his family discovered his talent for singing. At the age of **eight**, he joined the **Thái Bình Children's Arts and Culture Palace**, where he learned to play the electronic keyboard.
5. He was best known as the **lead singer of the rock band The Wall**.
6. He received many awards and honors, including an **MTV Europe Music Award** and a **Dedication Music Award**.
7. He was the **youngest child in a large, poor family**.
8. He began his artistic career by studying vocal performance at the **Department of Theatre, Hanoi College of Arts**, from **1993 to 1997**.
9. He graduated from the **Department of Economics, Vietnam National University, Hanoi**, in **2001**.
10. In **1994**, he and his friends formed a rock band.
11. His self-written singles, **"Cơn mưa ngang qua" (2012)** and **"Em của ngày hôm qua" (2013)**, launched his singing career.
12. He was the **leader of the band** from its formation until it disbanded in **2006**.
13. He wrote **more than 30 songs**, including the well-known song **"Road to Glory."**
14. However, his parents did not approve of his decision to pursue a singing career and wanted him to focus on his education. His father hoped that he would study business.
15. Despite his parents' wishes for him to study business, he actively participated in singing contests and performances at school.
16. He died of **cancer** on **4 November 2015**.

In Activity 1, students work in pairs to describe the physical appearance of the two singers from pictures and name their well-known songs, activating background knowledge as a warm-up for the reading task.

Next, in Activity 2, pairs read biographical facts and classify them by writing T for Trần Lập or S for Sơn Tùng M-TP, followed by whole-class answer checking and teacher feedback.

Finally, in Activity 3, students engage in a dynamic, mobile information-sharing task; Student A describes what they remember about Trần Lập while Student B listens, adds details, and asks questions, before they swap roles for Sơn Tùng M-TP. Students change partners multiple times to communicate with different classmates, which provides extensive speaking practice, reinforces reading content, and enables meaningful English use in authentic situations.

I believe that this adaptation is well suited to the students in my classes. It creates a more engaging and motivating learning environment by encouraging students to participate in discussions while drawing on familiar cultural contexts. By incorporating elements of Vietnamese culture into the lesson, the activities become more meaningful and relevant to learners' own experiences. As a result, students are more willing to express their ideas, actively participate in classroom interactions, and communicate with greater confidence. Furthermore, the familiarity of the topic reduces the cognitive load associated with generating ideas, enabling learners to focus more effectively on using the target language. Consequently, this adaptation is likely to enhance both students' motivation and their ability to produce English more naturally and fluently.

3. Conclusion

This paper highlights that adopting English as an International Language (EIL) principles, such as integrating local Vietnamese cultural content into teaching materials, enhances learner motivation and confidence in intercultural communication. While adapting materials presents challenges in time and resources, this "think globally, act locally" approach makes learning more meaningful and enables students to express their own identities. To implement these changes, teachers are encouraged to gradually incorporate EIL principles into their practice, enhancing both language proficiency and cultural expression.

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THEORETICO-METHODOLOGICAL FOUNDATIONS OF PHYSICAL CULTURE SPECIALISTS' TRAINING

The article is devoted to the professional training of specialists in the field of physical education and their professional and pedagogical skills. In this article, the author shares his thoughts and views on the education of future specialists. In fulfilling their professional duties, a physical education teacher must possess certain pedagogical abilities and a set of knowledge, skills, and abilities important for successful pedagogical activity.

Keywords:
physical culture, professional skills, and specialist competence.

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ТЕОРЕТИЧЕСКИЕ И МЕТОДОЛОГИЧЕСКИЕ ОСНОВЫ ПОДГОТОВКИ СПЕЦИАЛИСТОВ СФЕРЫ ФИЗИЧЕСКОЙ КУЛЬТУРЫ

Статья посвящена вопросам профессиональной подготовки специалистов в области физического воспитания и их профессионально-педагогического мастерства. В этой статье автор поделился своими мыслями и взглядами на воспитание будущего специалиста. Для выполнения своих профессиональных обязанностей учитель физкультуры должен обладать определенными педагогическими способностями, а также набором знаний, навыков и умений, важных для успешной педагогической деятельности.

Ключевые слова:
физическая культура, прфессиональное мастерство, компетентность специалиста.

Introduction

The sweeping changes of the early 21st century in the socio-economic, political, and cultural-cognitive spheres have impacted spirituality, consciousness, values, and behavior, complicating the process of improving the professional skills of physical education teachers. At the same time, the real social situation decisively demands the upbringing and formation of initiative and independence in physical education teachers, establishing new values: self-formation, self-education, and self-realization, which become the foundation for the establishment of a personality-oriented educational paradigm.

As O.A. Abdullina has noted: "the main shortcoming in the training of current graduates is the disconnection between theoretical knowledge and the skills for their practical application, which results in a low level of their practical skills and abilities" [2, p. 56]. Regarding this issue, E.P. Belozertsev has stated: "in the professional training of graduates of pedagogical educational institutions, there are a number of shortcomings: the inability to apply knowledge in specific pedagogical situations, the lack of skills for studying schoolchildren and establishing contact with them" [3, p. 7].

Typically, pedagogical abilities are built upon the foundation of general abilities such as observation, sharp intellect, attentiveness, creative imagination, tolerance, and others.

When studying the professional preparedness of future teachers in educational institutions, researchers focus their attention on those forms of knowledge that contribute to the development of practical skills and abilities. First and foremost, this concerns teaching practice. Educational-practical activity is the process of solving practical tasks aimed at fulfilling practical assignments that require the application of theoretical knowledge in practice. Such provisions regarding educational-practical activity are noted in the publications and works of scholars. V.S. Lednov notes that "teaching practice, as practicum in university conditions, is an organic part of the educational process of an educational institution and ensures the connection of creative training with the pedagogical practicum of students in educational institutions" [4, p. 41]. L.A. Lyubushkina, having researched the problems of adaptation of physical education trainee teachers to pedagogical activity, came to the conclusion that it is important to pay special attention to the organization and conduct of pedagogical practicum in schools, and most importantly, to the thorough methodological preparation of students, particularly regarding the particular methodologies of sports disciplines [5, p. 29].

"In the educational process, professional-pedagogical training is directed toward and partially implemented for the formation of pedagogical skills of future teachers. However, the potential and ways for

its improvement are very numerous," notes V.S. Vasilyeva. In practical classes, it is important to introduce procedures for pedagogical skills combined with activity analysis; the scope of teaching practice should be expanded to encompass the entire course of a specific subject. According to O.A. Abdullina, the organization of a complex of student activities includes the combination of educational-cognitive, educational-practical, and independent practical activities. Educational-practical activity, as a process of solving practical tasks aimed at fulfilling practical assignments in theoretical subjects, requires the application of theoretical knowledge in practical activity" [2, p. 57]. However, as E.P. Belozertseva notes, "in the system of training a physical education teacher, a well-grounded correlation of forms of student instruction and the time allocated for each form has not been developed. Changing the volume of hours allocated for sports disciplines in the professional-methodological cycle, which is fundamental for the methodological preparation of future physical education teachers, lacks a certain logic, is not scientifically substantiated, and has not been coordinated with the school curriculum" [3, p. 35].

The contradictory nature of the state of affairs in the educational-practical training of future physical education teachers is noted by E.P. Belozertseva.

"Strengthening the practical training of future physical education teachers depends on increasing the volume of pedagogical practicum within general professional training, which is applied to all pedagogical specializations and does not reflect the specifics of the future profession of a physical education teacher. The professional training of a physical education teacher (methods of physical education) lacks connection with the content of the school curriculum, for the implementation of which this training is intended. Also, there is no logical allocation of teaching hours for each section of the school curriculum; during the analyzed period of the faculties of physical education, the distribution of the grid of teaching hours and academic disciplines according to various areas of professional training has not been optimized. The following phenomenon testifies to the absence of specific criteria for assessing students' knowledge: in one curriculum, an exam is planned for a discipline, in another – a test, and in a third curriculum – a course project" [6, p. 63].

We agree with the arguments of this author and, within the framework of our research, analyze the educational materials of teaching practice. The following specialized disciplines of the physical education teacher specialization, which are of great professional importance in school activities, were subjected to analysis: "Gymnastics and Methods of Teaching It"; "Athletics and Methods of Teaching It"; "Sports and Outdoor Games and Methods of Teaching Them"; "Swimming and Methods of Teaching It"; "Rhythmic and Musical Education"; "Tourism and Methods of Teaching It."

All the mentioned disciplines are considered as forms of practical training. The content and essence of the educational-practical activity of a future physical education teacher includes the formation and development of professional programmatic details of the main pedagogical tasks: giving commands, individual line orders; reporting; explaining exercises; explaining games; formation, line-up; group positioning; selection and arrangement of exercise complexes for different parts of the lesson; choosing a position for leading instruction and games; demonstration of general physical exercises; knowledge of terminology; group organization; planning and developing tools, methods, and forms of physical education; conducting general physical exercises, special exercises, games, parts of a lesson, lesson (session), training; mistakes and errors; identifying main and secondary errors, analyzing them, indicating ways to eliminate them; providing assistance; conducting a methodological analysis of the lesson; teaching one person, several people, or everyone; refereeing: fulfilling duties: servicing competitions, conducting competitions; equipment and inventory; repairing, providing for exercisers, participants, games, lessons; location of activities and games; preparing, maintaining; working with planning documents; educational and competition documents.

Conclusion

The analysis of the teaching practice materials of the Faculty of Physical Education of the Pedagogical Institute has shown that the proportion of hours allocated to the aforementioned forms of specialist instruction is directed toward the aspect of practical training of future physical education teachers. It should be noted that a significant portion of the disciplines is not covered by teaching practice.

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ENGLISH TEACHING APPROACHES FOR GENERATION Z UNIVERSITY STUDENTS IN VIETNAM: A CONTEXT-SENSITIVE PEDAGOGICAL FRAMEWORK

Abstract

The rapid advancement of digital technology has transformed the ways university students learn English, particularly among Generation Z learners who have grown up in highly connected digital environments. In Vietnam, Generation Z students now represent the majority of learners in higher education, requiring English language teaching to adapt to their learning characteristics and technological experiences. This paper examines teaching approaches that are most appropriate for Generation Z students in Vietnamese universities through a review of recent literature on technology-enhanced language learning, blended learning, flipped classrooms, mobile-assisted language learning, project-based learning, gamification, and personalized learning. The study argues that effective English instruction should move beyond simply incorporating digital tools into classroom activities. Instead, successful pedagogy should integrate technology with communicative learning, collaborative activities, formative assessment, and learner autonomy. Considering the educational context of Vietnam, the paper concludes that a flexible learner-centered approach combining digital innovation with sound pedagogical principles provides the most effective direction for improving English language education for Generation Z learners.

Keywords:

Generation Z; English language teaching; higher education; Vietnam; blended learning; mobile-assisted language learning.

2. Introduction

The rapid development of digital technology has significantly reshaped higher education worldwide, particularly in the field of English language teaching (ELT). Today's university students have unprecedented access to information through smartphones, social media, online learning platforms, and artificial intelligence (AI)-supported applications. These technological changes have not only transformed learning environments but have also influenced students' expectations, learning habits, and classroom engagement.

Generation Z, generally defined as individuals born between 1997 and 2012, is the first generation to grow up in a fully digital environment. Their frequent use of mobile technologies and online communication has contributed to learning preferences that emphasize flexibility, multimedia resources, immediate feedback, and interactive learning experiences. Previous studies suggest that Generation Z learners tend to respond positively to technology-enhanced and student-centered learning environments, although they may also experience shorter attention spans and greater dependence on digital resources (Seemiller & Grace, 2016).

In Vietnam, Generation Z currently constitutes the majority of university students. At the same time, English proficiency has become increasingly important for academic success, international collaboration, and graduate employability. Although many Vietnamese universities have introduced digital learning platforms and online teaching resources, traditional teacher-centered instruction remains common in many English classrooms. This mismatch between students' learning preferences and conventional teaching practices may reduce learning motivation and classroom engagement. The original Vietnamese manuscript also emphasizes that while Generation Z students are highly familiar with digital technology, English teaching methods have not always evolved to meet their changing learning characteristics.

Therefore, identifying effective teaching approaches for Generation Z has become an important issue for English language education in Vietnam. Rather than focusing solely on technology adoption, teachers need to design learning environments that promote interaction, learner autonomy, authentic communication, and continuous feedback. Based on current international research and the Vietnamese educational context, this paper reviews contemporary teaching approaches and proposes pedagogical strategies that can enhance English language learning for Generation Z university students.

2. Literature Review

2.1. Generation Z as English Language Learners

Generation Z, generally defined as individuals born between 1997 and 2012, has grown up in an environment where digital technologies are integrated into everyday life. Compared with previous generations, they tend to prefer interactive, visually rich, and technology-supported learning environments. Studies have shown that Generation Z learners value flexibility, immediate feedback, collaboration, and authentic learning experiences (Seemiller & Grace, 2016). However, researchers also argue that frequent use of digital devices does not necessarily imply strong digital literacy or effective self-regulated learning. Therefore, English teachers should avoid assuming that all Generation Z students possess similar technological or academic abilities.

In Vietnam, these characteristics are increasingly evident among university students. Although many students are familiar with digital platforms and social media, their English proficiency, learning strategies, and digital competence vary considerably. Consequently, English instruction should provide both technological support and appropriate pedagogical guidance to develop language proficiency and learner autonomy.

2.2. Technology-Enhanced English Language Teaching

Recent studies have highlighted the growing role of educational technology in English language teaching. Mobile-Assisted Language Learning (MALL), learning management systems, artificial intelligence tools, and online collaborative platforms have expanded opportunities for language practice beyond the classroom. These technologies can improve vocabulary acquisition, pronunciation, listening practice, and learner engagement when they are integrated into well-designed instructional activities rather than being used as isolated technological tools.

However, technology alone does not guarantee better learning outcomes. The effectiveness of digital learning depends on instructional design, teacher support, formative assessment, and students' ability to regulate their own learning. Therefore, technology should be viewed as a pedagogical resource rather than an instructional objective.

2.3. Contemporary Teaching Approaches for Generation Z

Several learner-centered approaches have been widely recommended for teaching Generation Z students. Blended learning combines face-to-face instruction with online learning, providing greater flexibility while maintaining classroom interaction. Flipped classrooms encourage students to study learning materials before class so that classroom time can be devoted to communication, discussion, and problem-solving. Project-Based Learning promotes authentic language use through collaborative tasks, whereas gamification enhances motivation by incorporating game elements into classroom activities.

Previous research generally indicates that these approaches improve learner engagement, autonomy, and communicative competence. Nevertheless, their successful implementation depends on contextual factors such as teacher competence, institutional support, digital infrastructure, and students' readiness for independent learning. Therefore, no single teaching method is universally effective; instead, English teachers should adopt a flexible combination of learner-centered strategies that best fits the Vietnamese higher education context.

3. Current Challenges, Proposed Teaching Methods and Discussion

3.1. Current Challenges in English Language Teaching

Despite ongoing educational reforms, English language teaching (ELT) in Vietnamese universities continues to face several challenges in meeting the learning needs of Generation Z students. Although most students are familiar with digital technologies, many classrooms still rely heavily on teacher-centered instruction, textbook-based activities, and grammar-focused assessment. This mismatch often reduces students' motivation and limits opportunities for meaningful communication. Similar concerns were identified in the original Vietnamese manuscript, which highlights that many students prefer learning through digital media while classroom instruction has not fully adapted to these changing learning behaviors.

Another challenge is the considerable variation in students' English proficiency and self-directed learning skills. While some learners actively use online resources and AI-assisted applications to improve their language skills, others depend largely on teacher guidance and experience difficulties managing independent learning. Furthermore, unequal access to digital infrastructure, limited teacher training in educational technology, and large class sizes remain obstacles to implementing innovative teaching practices effectively.

3.2. Proposed Teaching Methods

To address these challenges, English instruction for Generation Z should adopt a learner-centered approach that combines technology with communicative pedagogy.

Blended learning is one of the most practical approaches because it integrates online learning with face-to-face instruction. Online platforms can be used to provide learning materials, vocabulary practice,

quizzes, and feedback before or after class, while classroom sessions focus on communication, collaboration, and problem-solving.

The flipped classroom is another effective strategy. Students study instructional videos or reading materials before class, allowing classroom time to be devoted to discussions, role plays, presentations, and other communicative activities. This approach encourages learner autonomy while maximizing opportunities for language practice.

In addition, Mobile-Assisted Language Learning (MALL) enables students to continue learning beyond the classroom through mobile applications such as Quizlet, Duolingo, Elsa Speak, or AI-supported learning tools. These applications provide flexible opportunities to practice pronunciation, vocabulary, listening, and speaking according to individual learning needs.

Project-Based Learning (PBL) and gamification can further increase learner engagement by encouraging students to complete authentic tasks such as creating podcasts, producing short videos, conducting interviews, or presenting solutions to real-world issues. Interactive platforms such as Kahoot or Quizizz may also enhance classroom participation through formative assessment and immediate feedback.

3.3. Discussion

The findings of this review suggest that no single teaching method is sufficient to meet the diverse learning needs of Generation Z students. Instead, effective English instruction requires the integration of multiple pedagogical approaches supported by appropriate educational technology. Digital tools should not replace teachers but rather facilitate communication, collaboration, learner autonomy, and continuous assessment.

For Vietnamese universities, successful implementation also depends on contextual factors including institutional support, teacher professional development, technological infrastructure, and students' readiness for independent learning. Therefore, rather than emphasizing technology itself, educators should focus on designing meaningful learning experiences that connect classroom activities with authentic language use and future professional communication.

Overall, a flexible combination of blended learning, flipped instruction, mobile-assisted learning, project-based activities, and formative assessment appears to provide the most appropriate pedagogical framework for teaching English to Generation Z students in Vietnam.

4. Practical Implications

The findings of this study provide several practical implications for English language teaching in Vietnamese universities. First, teachers should shift from knowledge transmission to learning facilitation by creating interactive and student-centered learning environments. Rather than relying primarily on lectures, classroom time should emphasize communication, collaboration, and problem-solving activities that encourage students to actively use English.

Second, technology should be integrated strategically rather than simply increasing the number of digital tools used in class. Learning management systems, mobile applications, AI-assisted writing tools, and online assessment platforms should support language learning objectives and promote learner autonomy instead of replacing teacher guidance.

Third, higher education institutions should invest in professional development programs that enhance teachers' digital pedagogical competence. Continuous training enables instructors to design blended courses, implement formative assessment, and effectively manage technology-enhanced learning environments.

Finally, curriculum designers should adopt flexible teaching models that accommodate different proficiency levels and learning preferences. Combining face-to-face instruction with online learning

resources, authentic tasks, and continuous feedback can better support the diverse needs of Generation Z students while preparing them for academic and professional communication in an increasingly digital world.

Table 1

Recommended English Teaching Framework for Generation Z Students in Vietnamese Universities

Challenge	Recommended Approach	Expected Outcome
Low classroom engagement	Blended Learning + Flipped Classroom	Increased participation and learning flexibility
Short attention span	Gamification and micro-learning activities	Higher motivation and sustained attention
Limited opportunities for communication	Project-Based Learning (PBL)	Improved speaking, teamwork, and critical thinking
Different learning abilities	Personalized Learning supported by LMS and AI tools	Individualized learning pathways and learner autonomy
Limited feedback in traditional classrooms	Formative assessment using Kahoot!, Quizizz, Mentimeter, or LMS	Immediate feedback and continuous learning improvement

Effective English teaching for Generation Z in Vietnam is achieved through the integration of learner-centered pedagogy, educational technology, authentic communication, and continuous formative assessment. These components collectively enhance learner engagement, language proficiency, and autonomous learning.

5. Conclusion

Generation Z students have introduced new opportunities and challenges for English language teaching in Vietnamese higher education. Their familiarity with digital technology and preference for interactive learning require instructional approaches that extend beyond traditional teacher-centered methods. However, technology alone cannot improve learning outcomes unless it is supported by sound pedagogical design and effective classroom interaction.

This paper has argued that a flexible combination of blended learning, flipped classrooms, Mobile-Assisted Language Learning, Project-Based Learning, gamification, and formative assessment provides an appropriate framework for teaching English to Generation Z learners in Vietnam. These approaches not only increase learner engagement but also foster communicative competence, learner autonomy, and the digital skills required in contemporary society.

Future research should conduct empirical investigations involving teachers and students from different Vietnamese universities to evaluate the effectiveness of these approaches in specific educational contexts. Such evidence will contribute to the development of sustainable pedagogical models for English language education during the ongoing digital transformation of higher education.

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LISTENING DIFFICULTIES AND LEARNERS' EXPECTATIONS OF EFFECTIVE LISTENING INSTRUCTION: EVIDENCE FROM VIETNAMESE EFL FRESHMEN

Abstract

A study of 164 first-year English majors at Hanoi University of Mining and Geology identified fast speech, limited vocabulary, unfamiliar accents, and connected speech as primary listening difficulties. Students preferred explicit strategy instruction and increased authentic material exposure, highlighting the need to blend strategy-based teaching with self-directed learning to improve listening proficiency.

Keywords:

EFL listening; listening difficulties; learner perceptions; thematic analysis;
Vietnamese university students; listening pedagogy

1. Introduction

Listening is a complex, less visible process essential for language learning, often challenging first-year students who struggle with real-time speech, reductions, and accents despite heavy exposure to English media (Field, 2008; Mendelsohn, 1998; Buck, 2001). This study examines the perceived difficulties, independent practices, and instructional expectations of 164 first-year English majors at a Vietnamese university to better align pedagogy with learner needs.

2. Literature Review

2.1. Listening comprehension as a multilevel process

Listening comprehension involves an interaction between bottom-up acoustic decoding and top-down contextual processing (Flowerdew & Miller, 2005; Nation & Newton, 2009). Goh (2000) categorizes listening failures into three cognitive stages: perception, parsing, and utilization. Consequently, common complaints like excessive speech rate often reflect internal processing limitations—such as slow lexical access, unfamiliar connected speech, or limited automaticity—rather than just the literal speed of the audio. Effective pedagogy must therefore move beyond broad problem identification to target these specific underlying processing demands and help students build phonological flexibility.

2.2. Learner practices and the role of digital exposure

Digital media expand out-of-class listening opportunities through films, podcasts, and social media, supporting vocabulary growth and motivation, though its value depends heavily on how learners engage with the material. Passive exposure, such as watching with first-language subtitles, often prioritizes plot over linguistic form, whereas structured practice utilizing explicit goals, prediction, selective attention, and reflection yields greater improvement (Graham & Macaro, 2008; Vandergrift, 2003). Additionally, incorporating micro-listening activities helps students focus on short speech stretches, diagnose comprehension errors, and notice connected-speech processes (Field, 2008). Ultimately, digital resources are most effective when integrated into a deliberate cycle of listening, diagnosis, and adjustment rather than treated as exposure alone.

2.3. Learner perceptions and effective listening instruction

Learner perceptions directly influence motivation, strategy choice, and persistence, as students often attribute listening failure to uncontrollable factors like speaker speed or low innate ability, which reduces self-efficacy (Graham, 2006). Teachers can counter this by making the listening process visible through

process-oriented instruction, shifting focus from answer checking to the sequence of decisions made before, during, and after listening. Research shows strategy instruction is most effective when taught in context, allowing learners to understand when and why specific strategies are useful (Goh, 2008; Rubin, 1994). Furthermore, addressing social and affective dimensions is crucial, as listening anxiety narrows attention, while peer discussions reduce uncertainty and reveal alternative processing methods. Consequently, effective instruction must combine linguistic support, strategy development, emotional reassurance, and opportunities for independent practice.

3. Method

3.1. Research design and context

The study used a qualitative-dominant descriptive design supported by frequency counts. It analysed three open-ended questions included in a broader questionnaire on listening comprehension strategies. The qualitative approach was selected because the study sought to identify how students described their difficulties and learning needs in their own words. Frequency counts were used to indicate the relative prominence of themes, not to convert the study into a purely quantitative analysis.

3.2. Participants

Participants were 164 first-year students majoring in English Language at Hanoi University of Mining and Geology, Vietnam. The group comprised 134 female students and 30 male students. Most described their English proficiency as A2 or B1. The students were taking foundational English courses and had studied English as a foreign language before entering university. Their transition to an English-major programme made them a relevant group for examining early university listening needs.

3.3. Instrument and data collection

The questionnaire was administered online through Google Forms. In addition to background and Likert-scale items used for a separate analysis, it contained three open-ended questions: ‘What is the biggest difficulty you face when listening to English?’, ‘What do you usually do to improve your English listening skills?’, and ‘What can your English teachers do to help you improve your listening comprehension?’ All 164 participants answered the first question, 149 answered the second, and 137 answered the third. Participation was voluntary, and responses were analysed anonymously.

3.4. Data analysis

The data were analyzed using semantic qualitative content analysis following Braun and Clarke’s (2006, 2021) thematic procedures to identify recurrent themes, with coding based on self-reported, non-exclusive responses. This approach used a transparent coding scheme to analyze direct content, although it was limited by the lack of follow-up interviews. Further details on the methodology can be found in the provided text.

4. Results

4.1. Reported listening difficulties

Table 1

Main listening difficulties reported by students (N = 164)

Theme	n	%
Fast speech and processing pressure	76	46.3
Limited vocabulary or unfamiliar words	60	36.6
Accent and pronunciation variation	57	34.8
Connected speech and reduced forms	20	12.2
Difficulty identifying main ideas or details	7	4.3
Concentration or memory problems	4	2.4
Grammar or complex sentence structure	3	1.8

Fast speech and processing pressure represent the most prominent barriers to English listening comprehension, with students often losing the message because they cannot keep up with native speakers. This challenge is further intensified by vocabulary limitations, as encountering unfamiliar words increases cognitive load and slows down lexical processing. Additionally, accent variation across British, American, and Australian English poses significant difficulties, revealing a lack of perceptual flexibility among learners. Finally, connected speech and reduced forms prevent students from recognizing words they already know in writing, causing them to misinterpret natural word linking as excessive speech speed.

4.2. Students' independent listening practices

Table 2

Practices used to improve listening (valid responses = 149)

Theme	n	%
Videos, films, television, YouTube, or social media	92	61.7
Podcasts, audio recordings, or stories	52	34.9
Regular or daily practice	49	32.9
Music or songs	43	28.9
Subtitles, captions, or transcripts	30	20.1
Vocabulary learning	14	9.4
Repetition or replay	10	6.7
Shadowing, imitation, or interaction	10	6.7
Dictation or transcription	6	4.0

The analysis indicates that while a majority of students actively engage with English through visual and audio media, their self-directed practices focus on passive consumption rather than active, structured learning processes. Despite reporting vocabulary and pronunciation as major difficulties, only a small minority employ intensive techniques like shadowing, repetition, or dictation, highlighting a need for more systematic approaches to improve listening comprehension. You can read the full analysis in the original study.

4.3. Expected instructional support

Table 3

Forms of teacher support requested by students (valid responses = 137)

Theme	n	%
More listening practice, exercises, or homework	54	39.4
Vocabulary and language explanation	33	24.1
Authentic or varied materials and accents	17	12.4
Feedback and explanation of answers	16	11.7
Explicit listening-strategy instruction	16	11.7
Repetition, pausing, segmentation, or slower delivery	14	10.2
Pronunciation or connected-speech instruction	9	6.6
Recommendations for self-study resources	7	5.1

Students frequently requested more structured listening practice, vocabulary explanations, and authentic materials to improve their comprehension. Additionally, they sought process-oriented activities—including shadowing, dictation, and greater playback control—along with teacher guidance to convert passive, independent listening into purposeful learning. Read the full study in this document.

5. Discussion

The findings indicate that first-year English-major students face significant listening difficulties due to fast speech, limited vocabulary, and unfamiliar accents, despite actively engaging in self-directed practice like watching videos and listening to podcasts. This suggests that informal practice alone is insufficient, highlighting the need for listening instruction that combines authentic practice with explicit strategy training to improve learners' confidence, metacognitive awareness, and autonomy.

7. Conclusion

A study of 164 first-year English majors in Vietnam identified fast speech, limited vocabulary, and accent variation as primary listening barriers, with students relying on media with subtitles over intensive practice methods like dictation and shadowing. Results suggest enhancing listening instruction by bridging independent digital listening with structured, diagnostic, and metacognitive classroom strategies to improve comprehension. For more information, visit the study's findings on listening difficulties, practices, and expectations.

Ethical Statement

Participation was voluntary. Students were informed that their responses would be used for research purposes, and the analysis was conducted on anonymized data. No email addresses or identifying personal information were included in the research report.

Conflict of Interest

The author declares no conflict of interest.

Data Availability

The anonymized dataset may be made available by the author for scholarly verification, subject to institutional and participant-privacy considerations.

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НОРМАТИВНО-ПРАВОВЫЕ ОСНОВЫ ФОРМИРОВАНИЯ НАУЧНО-ИССЛЕДОВАТЕЛЬСКОЙ КУЛЬТУРЫ БУДУЩЕГО УЧИТЕЛЯ

Аннотация

В статье представлен анализ нормативно-правовых документов, регламентирующих формирование научно-исследовательской культуры будущих учителей в системе высшего педагогического образования Российской Федерации. Автором рассмотрена многоуровневая система правового регулирования, включающая федеральные законы, указы Президента, постановления Правительства, федеральные государственные образовательные стандарты, профессиональные стандарты и локальные нормативные акты вузов. Целью исследования выступило выявление и систематизация нормативных оснований, определяющих требования к исследовательской подготовке

будущих педагогов. В качестве метода использован сравнительно-правовой анализ действующих нормативных актов. В результате установлено, что действующая нормативно-правовая база формирует чёткий государственный запрос на подготовку учителя-исследователя, однако между нормативными предписаниями и реальной образовательной практикой сохраняется значительный разрыв. Автором делается вывод о необходимости целенаправленного формирования научно-исследовательской культуры как интегративного качества личности, обеспечивающего этичное, осознанное и технологичное использование навыков исследовательской деятельности в педагогической практике.

Ключевые слова:

научно-исследовательская культура, будущий учитель, нормативно-правовые основы, ФГОС ВО, профессиональный стандарт «Педагог», педагогическое образование, исследовательские компетенции, научно-исследовательская деятельность студентов.

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REGULATORY AND LEGAL FOUNDATIONS FOR THE FORMATION OF SCIENTIFIC AND RESEARCH CULTURE OF FUTURE TEACHERS

Abstract

The article presents an analysis of regulatory documents governing the formation of scientific and research culture of future teachers in the system of higher pedagogical education of the Russian Federation. The author examines a multi-level system of legal regulation including federal laws, presidential decrees, government resolutions, federal state educational standards, professional standards and local regulations of universities. The aim of the study was to identify and systematize the regulatory foundations that determine requirements for the research training of future teachers. Comparative legal analysis of current regulatory acts was used as the research method. As a result, it was established that the current regulatory framework forms a clear state demand for training teacher-researchers; however, a significant gap remains between regulatory requirements and actual educational practice. The author concludes that it is necessary to purposefully develop scientific and research culture as an integrative personal quality.

Keywords:

scientific and research culture, future teacher, regulatory foundations, federal state educational standards, professional standard, pedagogical education, research competencies.

Введение

Современная система педагогического образования переживает период глубоких трансформаций, обусловленных динамичными изменениями в обществе, экономике и технологическом укладе. Перед педагогическими вузами стоит задача подготовки специалиста принципиально нового типа, способного не только передавать накопленные знания, но и самостоятельно вести научный поиск, критически оценивать информацию и внедрять результаты исследований в образовательный процесс [1]. Решение этой задачи невозможно без формирования у будущих учителей научно-исследовательской культуры, которая представляет собой интегративное качество личности, объединяющее мотивационно-ценностные установки, методологические знания, исследовательские компетенции и готовность транслировать научные ценности ученикам [2].

Значимость данного направления определяется не только внутренними потребностями педагогической науки и практики, но и прямым государственным запросом, зафиксированным в целом ряде нормативных документов различного уровня. Вместе с тем системного анализа нормативно-правовых оснований, в совокупности определяющих требования к исследовательской подготовке будущих учителей, в научной литературе представлено недостаточно. Цель настоящей статьи состоит в выявлении и систематизации нормативно-правовой базы, регламентирующей формирование научно-исследовательской культуры будущего учителя.

Методы исследования

В качестве основного метода использован сравнительно-правовой анализ действующих нормативных актов Российской Федерации, регламентирующих различные аспекты научно-исследовательской деятельности в системе высшего педагогического образования. Источниковую базу составили федеральные законы, указы Президента РФ, постановления и распоряжения Правительства РФ, федеральные государственные образовательные стандарты высшего образования, профессиональные стандарты, приказы Минобрнауки России, а также локальные нормативные акты образовательных организаций [2]. Документы анализировались с позиции содержащихся в них требований к исследовательской подготовке обучающихся и условиям её обеспечения.

Результаты исследования

Проведённый анализ позволил выявить многоуровневую структуру нормативно-правового регулирования формирования научно-исследовательской культуры будущих учителей, которую можно представить в виде пяти взаимосвязанных блоков.

Первый блок образуют федеральные законы, задающие общие правовые рамки. Федеральный закон от 29.12.2012 № 273-ФЗ «Об образовании в Российской Федерации» устанавливает правовые, организационные и экономические основы образования, закрепляя принцип содействия лицам, проявившим выдающиеся способности, в том числе в научно-исследовательской деятельности. Закон определяет цели интеграции образовательной и научной деятельности в высшем образовании: повышение качества подготовки обучающихся и использование достижений науки в образовательной деятельности [3]. Федеральный закон от 23.08.1996 № 127-ФЗ «О науке и государственной научно-технической политике» гарантирует субъектам научной деятельности свободу творчества, доступ к информации и подготовку кадров для научных организаций [4].

Второй блок составляют стратегические документы, определяющие государственные приоритеты в сфере науки и образования. Указ Президента РФ от 28.02.2024 № 145 «О Стратегии научно-технологического развития Российской Федерации» фиксирует долгосрочные цели и приоритеты, непосредственно влияющие на формирование научно-исследовательской культуры в вузах. Указ Президента РФ от 07.05.2024 № 309 «О национальных целях развития Российской Федерации на период до 2030 года и на перспективу до 2036 года» подчёркивает необходимость обеспечения глобальной конкурентоспособности российского образования [5]. Постановление Правительства РФ от 09.04.2010 № 219 направлено на создание условий для развития инновационной инфраструктуры вузов, а Государственная программа «Развитие науки и технологий» (утверждена постановлением Правительства РФ от 20.12.2012 № 2433-р) устанавливает цели и задачи в сфере науки, косвенно затрагивающие научно-исследовательскую работу будущих учителей [2].

Третий блок представлен федеральными государственными образовательными стандартами высшего образования (ФГОС ВО 3++), которые непосредственно определяют требования к результатам освоения образовательных программ. Анализ ФГОС ВО по направлениям подготовки 44.03.01 и 44.03.05 «Педагогическое образование» показывает, что исследовательская составляющая занимает в них одно из центральных мест. Будущие учителя обязаны освоить компетенции, отражающие

уверенное владение методологией системного и критического анализа (УК-1), способность определять круг задач в рамках поставленной цели для реализации проектной и исследовательской деятельности (УК-2), способность к осознанному выстраиванию траектории профессионального саморазвития (УК-6), готовность опираться на фундаментальные научные знания в ходе педагогической практики (ОПК-8), владение базисом современных методов исследования (ПК-1), способность проектировать развивающую образовательную среду (ПК-3), готовность использовать информационно-коммуникативные технологии в проектировании образовательного процесса (ПК-5) [6; 7].

Четвёртый блок образуют профессиональные стандарты. Профессиональный стандарт «Педагог» (утверждён Приказом Минтруда России от 18.10.2013 № 544н) требует от современного учителя не просто проведения уроков, а их выстраивания на основе достижений психологии и педагогики, умения применять результаты научных исследований на практике и организовывать самостоятельную исследовательскую работу школьников. Профессиональный стандарт «Педагог профессионального обучения, профессионального образования и дополнительного профессионального образования» прямо указывает, что педагог должен уметь применять результаты современных научных исследований в своей работе и развивать исследовательские навыки обучающихся [8].

Пятый блок составляют локальные нормативные акты образовательных организаций. В каждом университете функционирует комплекс документов, регулирующих научно-исследовательскую работу студентов: положения о научно-исследовательской работе студентов (определяющие цели, задачи, формы организации НИР и порядок оценки результатов), положения о студенческих научных обществах и проблемных группах, положения о конкурсах научных работ и студенческих конференциях, документы, регламентирующие порядок оформления отчётов о НИР и работу с интеллектуальной собственностью. Эти локальные акты разрабатываются в соответствии с федеральным и региональным законодательством и учитывают специфику конкретного вуза [2].

Обсуждение

Проведённый анализ свидетельствует о том, что действующая нормативно-правовая база формирует последовательный и многоаспектный государственный запрос на подготовку учителя-исследователя. Требования зафиксированы на всех уровнях: от стратегических документов, определяющих национальные приоритеты в сфере науки и технологий, до локальных актов конкретных университетов. При этом прослеживается чёткая логика: федеральные законы задают общие рамки, стратегические документы определяют приоритеты, ФГОС ВО конкретизируют требования к результатам подготовки, профессиональные стандарты фиксируют ожидания работодателей, а локальные акты обеспечивают организационный механизм реализации.

Вместе с тем констатирующий этап проведённой нами опытно-экспериментальной работы (100 студентов ФГБОУ ВО «Чеченский государственный педагогический университет», направление подготовки 44.03.05 «Педагогическое образование») показал, что между нормативными предписаниями и реальной практикой сохраняется значительный разрыв: у большинства обследованных студентов научно-исследовательская культура находится на начальном уровне сформированности [2]. Данный вывод согласуется с результатами исследований П.А. Амбаровой, Н.В. Шабровой и коллег [9], констатирующих преимущественно низкий уровень научно-исследовательской культуры студентов российских вузов, а также с наблюдениями О.С. Андреевой, О.А. Селивановой, И.В. Васильевой [10], подчёркивающих необходимость комплексной диагностики исследовательских компетенций будущих педагогов.

Причины разрыва, по нашему мнению, связаны не с недостатком нормативных предписаний, а

с отсутствием целенаправленного педагогического воздействия, обеспечивающего системное формирование всех компонентов научно-исследовательской культуры: мотивационно-ценностного, компетентностно-трансляционного, личностного и рефлексивного. Нормативная база создаёт необходимые условия и задаёт целевые ориентиры, но без специально разработанных программ, технологий и сред формирования эти ориентиры остаются декларативными.

Выводы

Нормативно-правовая база формирования научно-исследовательской культуры будущего учителя представляет собой многоуровневую систему, охватывающую федеральные законы, стратегические документы, образовательные и профессиональные стандарты, а также локальные акты вузов. Эта система формирует чёткий государственный запрос на подготовку педагога-исследователя. Однако наличие нормативных требований является необходимым, но недостаточным условием: реальное формирование научно-исследовательской культуры требует разработки и внедрения специальных педагогических программ и технологий, обеспечивающих системное воздействие на все её компоненты. Перспективы дальнейшего исследования связаны с проектированием и апробацией таких программ, а также с разработкой диагностического инструментария для оценки динамики формирования научно-исследовательской культуры обучающихся.

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THE ROLE OF VETERINARY MEDICINE IN GLOBAL DEVELOPMENT AND ECONOMIC GROWTH

Abstract

Veterinary medicine serves as a critical driver of global sustainable development, socioeconomic stability, and poverty reduction, particularly in developing economies. While traditionally viewed through the lens of animal health, the scope of veterinary science directly influences human well-being by securing rural livelihoods, strengthening trade capacities, and safeguarding public health. This article explores the multi-dimensional impact of veterinary infrastructure on community development, examining how livestock health management acts as an economic catalyst for smallholder farmers. It further analyzes the role of veterinary interventions in achieving food security and managing the cross-border transmission of animal diseases that threaten international market access. Ultimately, this study demonstrates that investment in veterinary education and clinical services is a foundational requirement for sustainable societal and economic advancement.

Keywords:
Veterinary Infrastructure, Socioeconomic Development, Rural L livelihoods,
Food Security, Disease Control.

Main Part

The relationship between veterinary medicine and macroeconomic development is deeply rooted in the asset value of livestock across low- and middle-income regions. For hundreds of millions of people worldwide, livestock represents far more than a source of dietary protein; animals function as living bank accounts, sources of draught power for crop cultivation, and primary drivers of household income. When infectious diseases strike these populations, the economic shock can plunge vulnerable rural families directly into absolute poverty. Veterinary professionals safeguard these vital biological assets by providing accessible vaccination campaigns, treating parasitic infestations, and delivering reproductive technologies. By suppressing animal mortality and optimizing herd health, veterinary medicine stabilizes the financial foundations of agrarian communities, empowering smallholder farmers to transition from subsistence production to commercial market participation.

Furthermore, national veterinary infrastructure acts as a primary institutional gatekeeper for international trade and macroeconomic development. Global agricultural markets operate under strict sanitary and phytosanitary regulations to prevent the spread of transboundary animal diseases. Developing nations seeking to export meat, dairy, or leather products must demonstrate verifiable disease-free zones and robust biological monitoring networks. A sophisticated national veterinary service provides the diagnostic capabilities, regulatory enforcement, and certification frameworks necessary to meet these demanding international standards. By building this scientific capacity, a developing nation can successfully open new export pathways, generate valuable foreign currency reserves, and stimulate industrial growth within its domestic agricultural and food processing sectors.

Gender Equity and Community-Level Development

At the grassroots level, the strategic deployment of veterinary services plays a transformative role in advancing gender equity and inclusive community development. In many traditional agricultural societies, women bear the primary responsibility for managing small livestock populations, such as poultry, goats, and sheep. Because these smaller animals require less capital to acquire, they represent an accessible pathway for women to secure independent financial means and household decision-making leverage.

When veterinary training initiatives actively target women—equipping them with basic diagnostic skills, nutritional knowledge, and animal husbandry techniques—the developmental ripple effects are profound. Healthier small livestock flocks yield immediate financial returns, which statistical data shows are disproportionately reinvested into family healthcare, childhood education, and improved domestic nutrition. Consequently, community-based veterinary outreach acts as a highly effective mechanism for reducing structural inequality and elevating rural standards of living.

Disaster Resilience and Climate Adaptation

As shifting global climate patterns accelerate environmental volatility, veterinary medicine is increasingly recognized as a cornerstone of ecological development and disaster resilience. Arid and semi-arid regions are experiencing prolonged droughts, erratic rainfall, and shifting vectors for parasitic diseases, which threaten pastoralist communities that rely entirely on livestock migration. Veterinary scientists work at the forefront of these challenges, developing climate-adaptive herd management strategies and monitoring the migration of climate-sensitive pathogens.

During natural disasters or acute environmental crises, emergency veterinary interventions—such as rapid feed distribution, emergency medical triage, and strategic deworming—prevent the catastrophic collapse of local livestock economies. By maintaining the health and resilience of these animal populations under environmental duress, the veterinary sector preserves the adaptive capacity of vulnerable human societies. This integration of veterinary science into broader climate resilience frameworks ensures that short-term environmental shocks do not turn into long-term developmental setbacks.

Conclusion

Veterinary medicine is an indispensable pillar of global development that extends far beyond the boundaries of animal welfare. By securing livestock assets, facilitating international trade, empowering marginalized demographics, and fostering climate resilience, the veterinary sector actively drives sustainable socioeconomic growth. Neglecting veterinary infrastructure leaves developing nations vulnerable to catastrophic economic losses, public health crises, and persistent rural poverty. To achieve long-term global prosperity and food security, international development frameworks must prioritize sustained investments in veterinary education, diagnostic networks, and rural clinical delivery systems.

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AGRONOMY AND AGRICULTURE: COORDINATING SCIENCE AND PRACTICE FOR GLOBAL FOOD SYSTEMS

Abstract

Agriculture remains the foundational bedrock of human civilization, while agronomy provides the precise scientific methodologies required to optimize crop production and manage land resources effectively. As global populations rise and arable land reserves face structural pressures, the integration of agronomic research into practical farming operations is crucial. This article explores the interconnected dynamics of agronomy and agriculture, highlighting how scientific principles guide field-level cultivation. It evaluates modern advancements in resource management, analyzes the socio-economic impacts of technological adoption on farming communities, and examines contemporary strategies for sustainable yield intensification. Ultimately, this study demonstrates that pairing robust agricultural production with advanced agronomic insights is essential for maintaining global food security and economic stability.

Keywords:

Crop Cultivation, Agronomic Management, Agricultural Systems, Sustainable Yields, Resource Optimization.

Main Part

The relationship between agronomy and agriculture represents the direct translation of biological, chemical, and environmental sciences into practical, large-scale food production. While agriculture encompasses the broader socio-economic and industrial systems of farming—including animal husbandry, supply chain logistics, and global markets—agronomy focuses specifically on the scientific mechanics of crop production and field soil management. Agronomists function as the primary scientific advisors within the agricultural sector, developing customized crop protection protocols, determining optimal sowing densities, and formulating precise fertilization regimes. By bridging the gap between controlled laboratory experiments and the variable conditions of open-field farming, agronomic science ensures that agricultural operations can achieve maximum efficiency while minimizing unexpected crop failures.

A primary area of focus within modern agricultural systems is the maintenance of long-term soil fertility and structural stability. Intensive farming practices, if left unmanaged by agronomic principles, can lead to severe nutrient depletion, soil compaction, and accelerated topsoil erosion. Agronomy addresses these structural threats by introducing scientifically verified land-management techniques into daily agricultural routines. These practices include the implementation of multi-year crop rotations, the integration of deep-rooted cover crops, and the application of conservation tillage methods that preserve the physical integrity of the soil profile. By maintaining a balanced soil architecture and protecting vital organic matter, these agronomic interventions directly preserve the natural production capacity of the land, ensuring that agricultural fields remain highly productive over multiple generations.

Precision Infrastructure and Smart Agricultural Operations

The contemporary evolution of agriculture is increasingly defined by the integration of data-driven agronomic technologies designed to optimize resource usage. Farmers worldwide are adopting precision

agricultural tools, such as automated tractors, aerial crop drones, and real-time soil nitrogen sensors. These advanced technologies allow agronomists to map fields with extreme precision, identifying localized variations in moisture levels, soil composition, and pest pressure across vast agricultural landscapes.

Through the implementation of variable-rate application systems, inputs such as water, macro-nutrients, and organic protective agents are deployed only where digital data indicates a specific requirement. This precise methodology replaces traditional blanket-application methods, significantly lowering chemical inputs and lowering the risk of chemical leaching into adjacent ecosystems. The continuous feedback loops provided by these digital monitoring systems enable farm managers to make rapid, evidence-based adjustments throughout the active growing season.

Economic Viability and Rural Farm Resilience

Beyond biological metrics, the intersection of agronomy and agriculture plays a critical role in strengthening the socio-economic resilience of rural farming communities. Smallholder and commercial agricultural operations alike operate under tight financial margins, highly vulnerable to market fluctuations and unexpected weather disruptions. Agronomic innovations—such as the development of fast-maturing crop varieties and low-cost water conservation systems—help stabilize seasonal farm revenues by lowering production risks.

Furthermore, agronomic extension programs deliver vital technical education directly to rural farmers, teaching them efficient weed management strategies and optimal post-harvest storage techniques. By reducing post-harvest losses and maximizing the marketable quality of harvested crops, agronomy directly increases household income levels within agrarian populations. This economic stabilization fosters community development, prevents rapid rural-to-urban migration, and provides farmers with the capital necessary to reinvest in safer, more efficient farming equipment.

Conclusion

Agronomy and agriculture function as interdependent pillars that support the continuity of global food networks and rural economic development. The continuous application of agronomic research ensures that agricultural practices remain adaptable, productive, and efficient in the face of shifting environmental and market conditions. By scaling up the use of precision technologies, improving soil preservation frameworks, and increasing the economic resilience of rural farms, the global agricultural sector can successfully navigate the challenges of modern food demands. Continued structural investment in agricultural education, public agronomic research, and localized extension frameworks is essential to empower the next generation of food producers.

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ИСКУССТВОВЕДЕНИЕ

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THE CULTURAL, HISTORICAL, AND BIOLOGICAL DIMENSIONS OF THE AKHAL-TEKE HORSE BREED

Abstract

The Akhal-Teke horse represents one of the oldest and most distinctive equine breeds in the world, serving as an enduring national symbol of Turkmenistan. Renowned for their exceptional physical endurance, specialized biological adaptations to desert environments, and a rare metallic coat sheen, these horses occupy a prominent position in both international equine sports and global cultural heritage. This article examines the historical evolution of the breed, analyzes its unique physiological characteristics, explores its contemporary cultural significance, and outlines modern conservation initiatives. By combining historical documentation with modern genetic insights, this study underscores the importance of maintaining breed purity and protecting this valuable genetic resource for future generations.

Keywords:

Akhal-Teke, Equine Physiology, Breed Preservation, Turkmenistan Culture, Genetic Heritage.

Main Part

The historical timeline of the Akhal-Teke breed spans over three millennia, rooted in the arid expanses of Central Asia. Originating in the territory of modern Turkmenistan, these horses were carefully developed by nomadic tribes who relied on their swiftness, intelligence, and resilience for long-distance travel and protective operations. The harsh climate of the Kara-Kum desert acted as a natural selector, forging a breed capable of traveling great distances with minimal water and forage. Historical records consistently highlight their participation in legendary endurance runs, including the famous 1935 expedition from Ashgabat to Moscow, which permanently demonstrated their unique stamina to the global community.

From a physiological perspective, the Akhal-Teke displays a highly refined, athletic conformation that distinguishes it from other warm-blooded or hot-blooded breeds. Characterized by long, clean lines, a narrow chest, a high-set neck, and a remarkably thin skin structure, the horse possesses an appearance often compared to a cheetah or a greyhound. The most visually striking feature of the breed is the metallic luster of its coat, particularly visible in cream, palomino, and buckskin color variations. Scientific evaluation indicates that this iridescent quality is caused by a unique cellular structure of the hair shaft, where the narrow opaque core allows maximum light refraction and reflection, creating a natural golden or silvery gleam.

Contemporary Achievements and Sports Performance

In modern equestrian disciplines, the Akhal-Teke continues to prove its high operational efficiency and athletic versatility. While their natural historical domain is long-distance endurance riding, individual representatives of the breed have achieved historic success in Olympic dressage and show jumping. The legendary stallion named Absent won the individual gold medal in dressage at the 1960 Olympic Games, establishing a high benchmark for the breed's capability in classical discipline, coordination, and responsiveness.

The movement pattern of these horses is characterized by a smooth, elastic stride often described as a gliding motion. This low-to-the-ground action minimizes energy expenditure when traveling over soft, sandy terrains and reduces the physical concussive forces experienced by both the animal and the rider. Today, through carefully managed training programs, their natural active temperament and loyalty are

utilized across various international sport arenas, keeping the breed visible to global enthusiasts.

Infrastructure and Breeding Regulations

The government of Turkmenistan places immense structural and scientific focus on the systematic preservation and development of the Akhal-Teke population. Large-scale modern equestrian complexes have been established to provide high-level veterinary care, training, and scientifically managed breeding conditions. To safeguard the ancient lineage, the international studbook remains strictly closed, ensuring that only purebred animals with verifiable oral and documented ancestry are integrated into the core gene pool.

Annual national celebrations, specialized research conferences, and international beauty contests highlight the societal respect directed toward these animals. These institutional measures are designed to control genetic diversity, prevent inbreeding depression, and manage specific hereditary conditions associated with limited populations. Through these structural frameworks, the state ensures that the traditional selection methodologies are combined with modern genomic insights.

Conclusion

The Akhal-Teke horse stands as a living monument of historical, biological, and cultural evolution. From its beginnings in the challenging desert environments of Central Asia to its modern role as an international sports horse and cherished national emblem, the breed has maintained its core phenotypic attributes and functional integrity. The combination of its distinctive physical appearance, athletic adaptability, and cultural value underscores the necessity of continuous global and domestic preservation efforts. By sustaining rigorous scientific studbook standards and advancing veterinary research, the future survival and prosperity of this unique equine treasure remain assured for global heritage.

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