EUROPEAN COMMON CURRICULUM FOR BACHELOR'S MICROBIOLOGY EDUCATION

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COMMON CURRICULUM ON MICROBIOLOGY

Microbiology, a science about microorganisms, is one of the major subjects and trends in training of biologists, biotechnologists, bioengineers, pharmacists and medical doctors at the level of Bachelor of Science Programs in colleges and universities of our time and widely distributed and adopted over Europe and the world as well. The study of microbiology will allow expanding the scientific horizons of students and gaining the knowledge necessary for follow-up.

Microbiology as a separate subject is taught in the training of specialists at B.Sc. Programs of

- *Biology, Biochemistry and Biotechnology, Medical Biochemistry, Biophysics and Bioinformatics*
- *Bio-based economy, Biotechnology and Food Safety*
- *Pharmacy, Human and Veterinary Medicine and other Health Sciences.*

Microbiology education has a long history and experience but should be permanently improved due to:

- New achievements in biology, basic and applied microbiology problems,
- Mobility of students and developing exchange programs especially in framework of the Bologna process in Europe,
- The labor market demands for microbiology specialists.

This all requires the development of a common (international) curriculum for training in Microbiology at B.Sc. level with common requirements or international standards and the general program or algorithm of microbiology teaching and training.

CURRICULUM GUIDELINES

The guidelines are not meant to be a mandate or an infringement upon academic freedom, but are curriculum recommendations.

LEARNING GOALS (MOTIVATION TO TEACH MICROBIOLOGY AND TRAINING MICROBIOLOGISTS)

Learning of Microbiology should be well motivated according to demands of different fields of human life and civil society. The goals are quite different but should be combined in one subject having academic and practical relevance. They can be:

For bio-based economy, industry and market:

- Using microorganisms in food products and pharmaceutical industry,
- Developing bio-energy production, including bio-ethanol, bio-methane and bio-hydrogen;

For science and environment:

- Scientific description and preservation of wide biodiversity, including microorganisms, in different regions over Europe;
    - Isolation and study of microorganisms in different ecological environment, discovering their role in nature and especially in ecological niches;

For medicine and health:

- Scientific description of microbiota and microbiome, and its role in the physiology of humans and animals,
- Understanding the world-wide impact of antimicrobial resistance,
- Monitoring and control of potentially dangerous microorganisms in nature and among habitants, developing new strategies against different pathogens,
- Control of biosafety especially of food imported and water supply;

For elementary, secondary and higher education:

- Biology education and general nature including life concepts (especially at secondary and high schools).

DIRECTIONS, MODULES AND GENERAL PROGRAM OF MICROBIOLOGY

Microbiology teaching at B.Sc. level appears generally in TWO DIRECTIONS (areas) –

(1) General (Basic) Microbiology and (2) Applied or Medical Microbiology.

It is proposed that the new program of General Microbiology may include THREE MODULES:

(1) the structure of the microbial cell, physiology, biochemistry and genetics of microorganisms;
(2) systematics, biodiversity and ecology of microorganisms;
(3) impact of microorganisms; types, methods and directions of microbial biotechnology; microorganisms as members of the physiology and agents of pathogenesis of plants, animals and humans.

It is important to highlight the objectives and output to ensure practical relevance.

PROGRAM ON GENERAL MICROBIOLOGY

Introduction and history of Microbiology

Introduction and major themes of microbiology. Microorganisms and their environment. The impact of microorganisms in nature and human life.

The discovery of microorganisms by Antonie van Leeuwenhoek. The role of L. Pasteur and R. Koch in the formation of microbiology as a science. The value of work of M. Beijerinck, S. N. Winogradsky, A. Fleming and others. Carl Woese and the impact of the taxonomy based on phylogenetic relationship. The main directions in development of modern microbiology.

Structure of microorganisms

Prokaryotic and eukaryotic organisms.

Structure of prokaryotic cell. Cell morphology and sizes of prokaryotes. Microscopy.

The role of various chemical compounds in the formation of cell structures and the functioning of bacteria. The chemical composition, synthesis, structure and functions of the bacterial and archaeal cell wall. Peptidoglycan. Differences in the cell walls of Gram-positive and Gram-negative bacteria, acid-fast bacteria. Bacteria without cell wall like Chlamydia and Mycoplasma. Bacterial spheroplasts and protoplasts: production methods, properties, applications. L-forms of bacteria and their characteristics. The chemical composition, organization and functions of the surface structures of the bacterial cell (capsules, covers, villi). The cytoplasmic membrane: chemical nature, structure and functions. Transport of substances through the cytoplasmic membrane. Derivatives of the cytoplasmic membrane and their functions. The cytoplasm of bacteria; chemical composition and

organization. Intracytoplasmic inclusions; their nature and importance to the cell. Organelles of the cytoplasm and their functions. Bacterial cell nucleoid: chemical and structural organization, functions. DNA replication in bacteria. Replicon concept. Regulation of cell division. Organelles of the movement of bacteria. The structure, location on the cell and the functioning of bacterial flagella and swimming motility. The movement of spirochetes and bacteria with sliding type of movement. Pilli. The structure, chemical composition and properties of bacterial endospores. The practical importance of spore formation.

Eukaryotic microbial cells (yeasts, filamentous fungi, protozoa and algae); major eukaryotic cell structures: the nucleus, mitochondria, chloroplasts, peroxisomes and others.

Biochemistry of microorganisms

Types and main purposes of metabolic reactions in microbes, general characteristic and features. Energy metabolism. Sources of energy in microorganisms; energy rich compounds. Chemosynthesis and photosynthesis.

Characterization of types of energy metabolism. Pathways of glucose catabolism in microorganisms: glycolysis, pentose-phosphate and 2-keto-3-deoxy-6-phosphogluconate pathways. Energy output of various paths glucose catabolism. Gluconeogenesis. Fermentation. The fermentation pathways of carbohydrates and other compounds. Alcoholic fermentation in yeasts and bacteria, lactic acid homo- and hetero-fermentation; acetone-butanol fermentation, propionic acid fermentation, mixed acid fermentation.

Aerobic respiration is one type of energy metabolism. Tricarboxylic acid cycle (Krebs or citric acid cycle), anaplerotic pathways, including glyoxylic pathway. Anaerobic respiration. Respiratory chains: complexes and electron transfer mechanisms. Donors and electron acceptors used by various microorganisms in anaerobic respiration; nitrate, sulphate and fumarate respiration.

Photosynthesis in archaea, bacteria and microalgae. The structure of the photosynthetic apparatus of a bacterial cell. Photosynthetic pigments. Photosynthesis with and without the release of molecular oxygen. The use of light energy by halophylic archaea.

Chemiosmotic coupling and the synthesis of ATP in the respiratory and photosynthetic chains of microorganisms.

Assimilation of biogenic elements.

Biosynthesis of amino acids by bacteria; major predecessors and biosynthesis pathways. The biosynthesis of carbohydrates, nucleotides, fatty acids and phospholipids. Assimilation of carbon dioxide by autotrophic and heterotrophic microorganisms.

Secondary metabolism. Production of antibiotics, vitamins and alkaloids.

Regulation of enzyme activity in bacteria. Multivalent, cumulative and sequential inhibition of enzyme activity. Regulation of the synthesis of enzymes in bacteria. The operon principle of the organization of bacterial chromosomes. Inducible operons and their functioning mechanisms. Catabolite repression. The mechanisms of functioning of repressive operons. Regulons, modulons.

Genetics of microorganisms

Microbial genome.

The variability of microorganisms. Evidence of the mutational nature of changes in hereditary traits in bacteria. The concept of adaptation of microorganisms. Modification variability in bacteria.

Mutations in bacteria. Mutagenic factors. The practical use of mutations. Selection methods of bacterial mutants.

Characterization of the methods of genetic exchange in bacteria. Bacterial transformation. Discovery, mechanism, stages of transformation. Competence recipient cells during transformation and its nature. Practical value transformations. Bacterial conjugation; discovery, mechanisms, basic features as a way to exchange of genetic information. Stages of conjugation. The practical significance of conjugation. Donor and recipient bacteria and their characteristics. Sexual factor of *E. coli*, its organization and functions. Types of donor bacteria; the mechanisms of their formation and the main differences. Features of offspring formed in crosses using various donors. Bacterial transduction; discovery, mechanisms and features. Types of transduction. The use of transduction for practical purposes. The difference between transduction and phage conversion. The technique of crossing bacteria. Principles of selection of recombinants.

Bacterial cell plasmids; nature, organization, properties and significance for a bacterial cell. Interaction of plasmids with a chromosome. The use of plasmids in genetic engineering. Migratory genetic elements of bacteria (IS-elements, transposons, phage transposons). Bacterial cell restriction and modification systems: detection, mechanism, meaning for the cell. Types of restriction enzymes.

Growth and physiology of microorganisms

Microorganisms growth and cell division.

Nutrient media in Microbiology (classification, manufacturing principle). Sterilization and disinfection. Methods for sterilization of media, thermolabile compounds, air, disposable materials.

Cultivation of aerobic and anaerobic microorganisms. Cumulative media; methods for their preparation. Pure microorganism cultures; methods for their preparation. Cell growth and bacterial population. Balanced and unbalanced growth. Batch and continuous cultivation of microorganisms. The main parameters of cell growth: generation time, specific growth rate, biomass yield, economic coefficient. The patterns of growth of pure crops during periodic cultivation. Growth curve, characteristic of individual phases. The growth of microorganisms during continuous cultivation. Main parameters of continuous cultivation, Dilution rate, critical dilution rate. Synchronous cultures, methods for their preparation and significance. The cultivation of immobilized cells of microorganisms. Methods for the quantification of microorganisms. Maintenance methods (storage) for cultures of microorganisms. Bioreactors for cultivation of microorganisms, their types and design.

The action of factors of a physical nature on the vital activity of microorganisms. Effect of temperature and other environmental physical and physicochemical factors on microbial growth. The nature and mechanisms of the action of chemicals on the vital activity of microorganisms. Repair of DNA damage in microorganisms (photoreactivation, excision and recombination repair, SOS response). Molecular mechanisms of repair processes. The practical use of chemical and physical factors. Sterilization methods used in microbiological practice. Methods for determining the sensitivity of microorganisms to UV radiation.

Nutrition of microorganisms. Phototrophs and chemotrophs. Autotrophs and heterotrophs. Chemicals as nutrient substrates. Enzymatic mechanisms of microorganisms, providing utilization of

nutrients. Constitutive and inducible enzymes. Exo- and endo-enzymes. Determination of the enzymatic activity of microorganisms. Microbial cell growth factors. Auxotrophs and prototrophs. Physiological nutrition groups bacteria.

Antimicrobial compounds; their nature and mechanism of action on the microbial cell. The use of antimicrobials for practical purposes. Methods for determining the sensitivity of microorganisms to antimicrobials. Antimicrobial resistance: mechanisms. Importance of adequate use of antimicrobials to avoid the selection of multi-resistant microorganisms.

Systematics, biodiversity and ecology of microorganisms

Microbial evolution and systematics. The principles of taxonomy of microorganisms. Classification, nomenclature and identification of microorganisms. Numeric taxonomy. Phylogenetic taxonomy. Bioinformatic tools used in classification and identification of microbes. Genetic, phenotypic and chemo-taxonomy. Main superphyla and phyla. The principles of species identification of microorganisms. Culture collections and genomic and protein data bases.

Taxonomic diversity of bacteria, archaea and eukaryotic microorganisms. Microbial communities. Culture-dependent and culture-independent analysis of microbial communities. Biofilms.

Microbial ecology. Terrestrial environment; soil microorganisms. Aquatic environment; freshwater, marine (deep sea), hydrothermal microorganisms. Extremophilic microorganisms. Symbiosis between microorganisms. Saprophytes and parasites. Syntrophy. Plants and animals as microbial habitats.

Nutrient cycles in nature. Carbon, nitrogen, sulfur and other cycles. The spread and role of denitrifying bacteria in nature. Biological properties, distribution and importance of sulfate reducing bacteria. Biological properties, ecology and role in the nature of methanogenic archaea. Human impact on the carbon and nitrogen cycles.

Regional biodiversity of microorganisms and environmental problems.

Viruses

Structure of viruses. Viral genomes and evolution. Replication of bacteriophages and animal viruses. Synthesis of viral components; interaction with the cell. Viral integration: Lysogenic cycles. Viral diversity and ecology. Viruses and cancer.

Impact of microorganisms. Introduction to microbial biotechnology

Microorganisms of the build environment. Microbes and climate change. Microorganisms in mineral recovery and acid mine drainage. Methanogenesis. Microorganisms in bioremediation. Microorganisms in wastewater and drinking water treatment. Microbially influenced corrosion. Food spoilage.

Types, methods and trends of microbial biotechnology. Genetic engineering of microorganisms. Recombinant DNA technology. Cloning of genes in the cells of microorganisms. Successes and prospects of genetic engineering. Cell engineering. Fermentation technologies. Microorganisms in food production. Food biosafety. Bioenergy production. Microbial fuel cells. Microbial synthesis technologies of end products.

Pathogenic microorganisms

The “One Health Triad”: human, animal and environment are connected in one single health system. Bacterial and eukaryotic microorganisms pathogenic for humans, animals and plants: Their characteristics and virulence factors. Human and animal normobiota and its role in human health. Invasiveness, aggressiveness, toxigenicity. Microbial toxins, their classification, chemical nature and properties. The mechanisms of toxin production and their effects on a susceptible organism. Therapeutic use of toxins. Antimicrobial resistance mechanisms. Bacteriophages and their role to combat of pathogenic bacteria. Prevention of microbial diseases.

Importantly, a certain part of the program (up to a quarter of volume) for Microbiology can include regional microbiology problems associated with microbial diversity, prevention of microbial diseases and environmental problems.

Thus, particular attention is paid to prokaryotic microorganisms (archaea and bacteria), since eukaryotic microorganisms (microscopic fungi, algae and protozoa) are also studied in the other courses. A variety of physiological, biochemical and genetic properties of microorganisms is considered in the context of their distribution and existence in various ecological niches.

ASSESSMENT (IMPLEMENTATION): TEACHING AND LEARNING METHODS

Current trends of assesment (teaching/learning) are to combine new and interdisciplinary subjects with professional ones for training students according to the requirements of the labor market (food and beverages industry, pharmaceutical companies, clinical and safety labs, monitoring centers, water supply companies, education etc) and apply active learning methods.

Implementation of curriculum should include

- interactive sessions – instead of formerly traditional lectures,
- multiple-choice questions in class using a personal response system and new learning methods and approaches
- Core concepts, fundamental statements; New discoveries and revisions of old concepts and theories

SOME CORE CONCEPTS AND FUNDAMENTAL STATEMENTS

Core concepts and fundamental statements have been well represented in ASM Recommended Curriculum Guidelines for Undergraduate Microbiology (S. Merkel, J Microbiol. Biol. Educ. 2012, 13, 32-38;
http://www.asm.org/images/Education/FINAL_Curriculum_Guidelines_w_title_page.pdf**).**

SUBJECTS ESSENTIAL FOR LEARNING GENERAL MICROBIOLOGY

Microbiology learning should develop ability to communicate and collaborate with other disciplines.

Some subjects have close relation to Microbiology so they are essential for learning Microbiology; they would be: Before learning of Microbiology

- Organic Chemistry,

- Cell Biology,
- General Biochemistry,

And in parallel with Microbiology

- General Physiology,
- Molecular Biology,
- General and Molecular Genetics,
- Immunology.

ALGORITHM OF GENERAL MICROBIOLOGY

The algorithm of General Microbiology includes the problematic (interactive, student-centered and engaged learning) lectures, practical classes and laboratory work, tests, and various forms of individual self-work. The ratio of lectures and laboratory work is offered approximately EQUAL.

More attention has to be paid to the development of laboratory practical skills. Laboratory work must be carried out by general (international) protocols recommended by laboratory manuals, which are acceptable for Europe or will be developed. The following reference books of Microbiology lab manuals might be recommended:

- Microbiology Lab Manual: Principles and Applications by S.A. Norrrell & K.E. Messley, Prentice Hall – 1999
- Microbiology: Laboratory Manual by J.G. Cappuccino & N. Sharman, Pearson - 2011
- Laboratory Experiments in Microbiology by T.R. Johnson & C.L. Case, Benjamin/Cummings Pub. Co - 12th Edition – 2019

Video materials could be also recommended: Fundamentals of Microbiology Laboratory Videos. J. C. Pommerville, 11st Edition, 2018 **(**https://www.jblearning.com**)**.

Also important are consistent actions for the implementation of the algorithm to include assessment of the knowledge and learning feedback.

Moreover, research/research methods are of interest nowadays and may (should) be included as Individual work (literature review, popular (cartoon) presentation, experimental study, etc.) in the program for Microbiology as a subject

- at lab
- outside (at home).

With all this, the credits of 3-6 are recommended for General Microbiology at least.

SKILLS TYPES INCLUDING LABORATORY

Successful microbiology work demands reliable precision in

- safe handling of microorganisms and aseptic technique,
- sampling and identifying microbes,
- observing their characteristics and behavior,
- applying biological theories to observations
- drawing accurate conclusions based on experimental data, known facts and concepts, original research (findings).

General microbiology lab specific skills to be acquired and developed as:

- Preparation of nutrient media and culturing of bacteria and yeasts: Inoculation and plating,
- Using of a light microscopy to characterize and identify bacteria,
- Application and performing physiological and biochemical tests to differentiate bacteria,
- Extracting DNA from bacteria and eukaryotic microorganisms,
- Operating of standard and new microbiology equipment,
- Processing data.

Therefore, Microbiology learning has to develop skills including practical (laboratory) ones in different aspects for:

- Applying knowledge and understanding; Is capable to analyze the basic experimental facts
- Communication, ICT and numeracy skills; ability to apply or to transfer the acquired knowledge and methods to other specialty areas or areas of biology specialization
- Generic cognitive skills (including judgments): applying critical thinking, analysis and judgement to the problems of Biology.