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PART IV:INTERDISCIPLINARY SCIENCE

14TH INTERNATIONAL SYMPOSIUM, LJUBLJANA, APRIL 17, 2026

EDITED BY

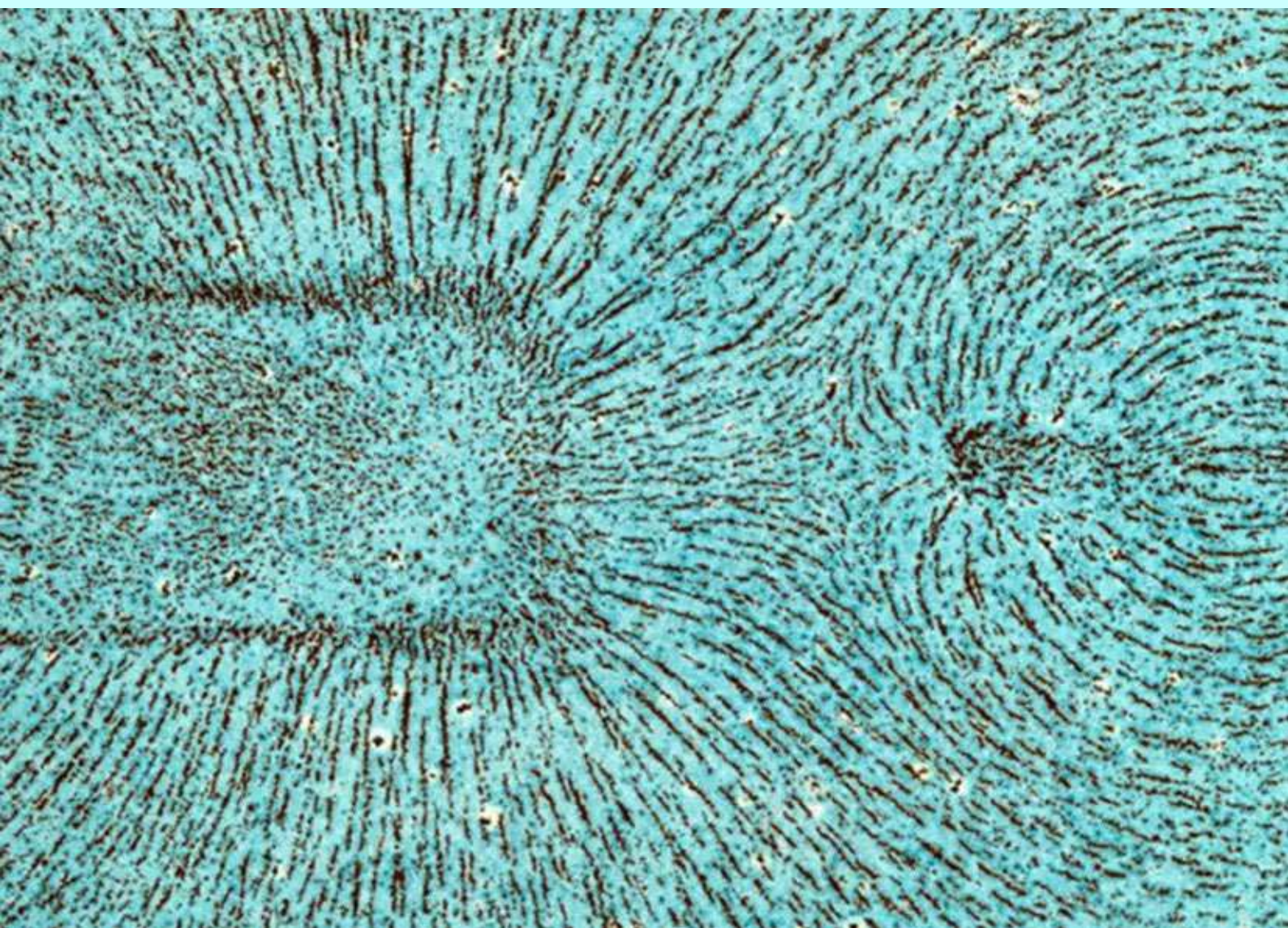
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UNIVERSITY OF LJUBLJANA



Socratic Lectures

14th International Symposium, Ljubljana, April 17, 2026

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Program of the Symposium Socratic Lectures, April 17, 2026, 10:00 – 17:00 (Ljubljana time)

10.00 Welcome to participants: Veronika Kralj-Iglič

10.10 - 10.45 Plenary lecture: Sebestova Janouskova Olga: Extracellular Vesicles: nanosize natural particles with BIG biological impact

11.00 Scientific sections

Section 1: Medicine (Chairs Amon Mojca, Janša Jošt)

- 11.00 - 11.30** Kneževič Ivan: From Bedside to Bench: Translating Clinical Needs into Next-Generation Regenerative Biomaterials
- 11.30 - 11.45** Jelenc Matija: Preoperative Planning of Aortic Valve Repair in Cardiac Surgery
- 11.45 - 12.00** Janša Jošt, Amon Mojca, Hawlina Simob: Beyond Tumour Biology: The Role of Body Composition in Risk Stratification of NMIBC Surgery
- 12.00 - 12.15** Trotošek Blaž, Serša Gregor, Đokić Mihajlo: Electrochemotherapy - From Lab to Clinics
- 12.15 - 12.30** Kšela Juš, Racman Mark: Environmental Determinants of Cardiovascular Disease: Integrating Air Pollution, Metal Exposure, and Early Vascular Pathology
- 12.30 - 12.45** Amon Mojca: Exercise Physiology and Ergonomics – Bridging Physiological Extremes to Pathology
- 12.45 - 13.00** Kreča Žak, Strajnar Jan, Poredoš Jana, Nikolov Žan, Mali Katra, Boc Anja: Upper limb mobility after breast cancer surgery: pathoanatomical changes and šhysiotherapy approaches

Section 2 : Biomedicine (Chair Vauhnik Renata, Manoso-Hernando Daniel)

- 11:00 Keynote lecture:** Manoso-Hernando Daniel, Mateo-Quel Jesús, Villaverde-Rúa Mario, Fernández-Llamazares-Mateos Gabriel: Comparison of shoulder muscle activation and strength between sides during the Closed Kinetic Chain Upper Extremity Stability Test and its modified version in patients with rotator cuff-related shoulder pain
- 11:30 - 11:45** Jelen Matic, Weber Daša, Kežžar Nataša, Vauhnik Renata: Correlation of Knee Joint Stabilization Force With Anterior and Mediolateral Rotational Laxity Using the Dyneelax Arthrometer
- 11:45 - 12:00** Breznik Katarina, Potočnik Maja Marija, Vauhnik Renata, Frangež Maja: Electrical potential of the deep abdominal muscles during different exhalation techniques
- 12:00 - 12:15** Fijavž Staš, Jerebic Mark, Milaković Rina, Olip Nejc, Paladin Maša, Žager Marcuš Valerija, Gošnak Dahmane Raja: The role of radiation therapists in addressing the side effects of radiation exposure
- 12:15 - 12:30** Strnad Špela, Jevsnič Podlesnik Mojca, Jamnikar-Ciglenecki Urska: Short Food Supply Chains in Slovenia: Main Challenges and Future Growth
- 12:30 - 12:45** Ančimer Špela, Antončič Jerca, Hrovatin Ajda, Piliš Klemen Aleš, Vauhnik Renata: Medial discoid meniscus treated with platelet-rich plasma: A case report
- 12:45 - 13:00** Vovk Lara, Vauhnik Renata: Physiotherapy approach in linear scleroderma of the lower limb: A case report

Section 3: Extracellular particles (Chair Pocsfalvi Gabriella, Turiak Lilla)

- 11:00 - 11:25** Keynote lecture: De la Cuesta Fernando: Identity Markers for Plant EVs
- 11:25 - 11:50** Keynote lecture: Ambrosone Alfredo: Exploring Plant Extracellular Vesicles for Innovative bio-based therapies
- 11:50 - 12:00** Chang Yu-Hsin: μ Pulse TFF optimization for plant-derived extracellular vesicle isolation
- 12:00 - 12:10** Patil Pradnya, Pratiwi Feby, Tokarchuk Kateryna, Oh JaeWon, Kim Kwang Pyo, Vainio Seppo: Comparative Proteomic Analysis of Strawberry-Derived Nanovesicles and Total Protein Extracts from Biodynamic and Conventional Strawberries
- 12:10 - 12:20** Moubarak Maneea: Plant tissue culture
- 12:20 - 12:30** Bautista Hernandez Olivia del Carmen: From Cells to Cytokines: A Microfluidic Approach to Study Anti Inflammatory Effects of Plant-Derived Nanovesicles

- 12:30 - 12:40 Kralj-Iglič Veronika, Romolo Anna, Istileulova Yelena, Iglič Aleš: Coacervation: a mechanism of extracellular particle formation
- 12:40 - 12:50 Murto Henri: EV lab on a farm and new possibilities of regenerative farming for circular economy
- 12:50 Discussion

Section 4: Biophysics (Chairs Iglič Aleš, Beke Somfai Tamas)

- 11:00 - 11:30 **Keynote lecture:** Beke Somfai Tamas: Supramolecular antibiotics killing Gram-negative bacteria by mechanical membrane damage
- 11:30 - 11:45 Mercaldo Beatrice, Anna Romolo, Matej Hočevár, Matic Kisovec, Apolonija Bedina Zavec, Boštjan Korenjak, Aleš Iglič, Antonio DiLoria, Veronika Kralj-Iglič: Measuring density and viscosity of samples as an improvement of interferometric light microscopy
- 11:45 - 12:00 Arko Matevž, Matej Hočevár, Boštjan Korenjak, Iglič Aleš, Kralj-Iglič Veronika: Extracellular particles from equine and bovine milk
- 12:00 - 12:15 Korenjak Boštjan, Romolo Anna, Tratenšek Armando, Nemec Svete Alenka, Drobne David, Aleš Iglič, Vladimira Erjavec, Veronika Kralj-Iglič: Comparison of extracellular vesicle characteristics of human and dog
- 12:15 - 12:30 Mesarec Luka, Kralj-Iglič Veronika, Kralj-Samo, Iglič Aleš: Effect of the concentration of curved rod-like molecules on the equilibrium shapes of two-dimensional shells
- 12:30 - 12:45 Drab Mitja: Modeling active anisotropic membrane inclusions
- 12:45 - 13:00 Klemenc Ana: Applications of surface-enhanced Raman spectroscopy in biomedicine

Section 5: Materials (Chairs Kralj-Iglič Veronika, Juan Alfredo)

- 11:00 - 11:30 **Keynote lecture:** Patrignani Mauro, Weber Jennifer, Bechthold Pablo, González Estela, Sainz Díaz Ignacio, Sandoval Mario, Figueroa Carlos, Jasen Paula, Juan Alfredo: Exploring the Effect of Oxygen on SiC/Fe Interfacial Adhesion Using Experiments and Quantum Mechanics simulations
- 11:30 - 11:45 Bar Laure, Lavrič Marta, Caf Maja, Kralj Slavko, Kumar Sadhu Raj, Škarabot Miha, Losada-Pérez Patricia, Iglič Aleš, Cordoyiannis George: Lipid-phase-modulated interactions of gold nanoparticles with supported vesicular membranes
- 11:45 - 12:00 Cepec Eva, Godič Torkar Karmen, Šunta Urška, Griessler Bulc Tjaša, Manjarres Castro June, Istenič Darja: The Microbial Comeback: Challenges in Achieving Long-Term Axenic Microalgal Cultures
- 12:00 - 12:15 Bosković Neda: Microplastics in aquatic environment: insight from research in Montenegro
- 12:15 - 12:30 Karas Tjaša: Applications of Machine Learning in Brillouin Spectroscopy
- 12:30 - 12:45 Žarković Lara, Zupan Iza, Hankić Larisa, Žager Marcuš Valerija, Gošnak Dahmane Raja: Patient Safety in Radiotherapy: Human Factors and Error Prevention Systems
- 12:45 - 13:00 Bensa Maja, Jevšnik Podlesnik Mojca, Vovk Irena: Consumers' food safety concerns in a changing food landscape

Section 6: Complexity (Chairs Jelen Andreja and Švajger Blaž)

- 11:00 - 11:30 **Keynote lecture:** Sojecka Agata Angelika, Drozd-Rzoska Aleksandra: New Insights into Global and Local Human Population Changes
- 11:30 - 11:45 Jelen Andreja: Formation of complex patterns in Ferromagnetic High-Entropy Alloys which leads to magnetic softness
- 11:45 - 12:00 Župec Matjaž: Power-law and Tsallis distribution in football goal scoring
- 12:00 - 12:15 Sgerm Jaka, Kodrin Marcel: Visualising order parameter spaces
- 12:15 - 12:30 Dovnik Damjan: Quantum Hall Effect
- 12:30 - 12:45 Fras Rene: Electrocaloric effect
- 12:45 - 13:00 Michelini Sara, Bele Marjan, Tatti Francesco, Drobne Damjana, Mandič Mulec Ines, Šimunovič Katarina: Influence of in vitro model complexity on Campylobacter jejuni–host interactions

Section 7: Soft matter (Chair Kralj Samo, Drozd-Rzoska Aleksandra)

- 11:00 - 11:30 **Keynote lecture:** Rzoska Sylwester J, Drozd-Rzoska Aleksandra: The New Philosopher's Stone: 'hard' & 'soft' matter under extreme pressures
- 11:30 - 11:45 Melani Potrč: Dynamic Light Scattering as a Tool for Characterization of DNA-quadruplexes

- 11:45 - 12:00 Javornik Tim, Kravos Iztok: Kibble Zurek Mechanism in Confined Geometries
 12:00 - 12:15 Zid Maha: Topological charge conservation in planar confinements
 12:15 - 12:30 Hölbl Arbresha: Weakly disordered soft matter
 12:30 - 12:45 Ribaš Anja: Chaotic Metasurfaces
 12:45 - 13:00 Švajger Blaž: Percolation in electrocaloric applications

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- 11:00 - 11:15 Borghesan Mariapia: STEAM as a Catalyst for Educational Innovation
 11:15 - 11:25 Brogna Daniela: STEAM Hackathon: Sky patterns on the ceramic road between IZNIK and SALERNO
 11:25 - 11:45 Simac Anita: When Geometry Becomes Art: Bridging Art and Geometry in the Classroom
 11:45 - 12:00 Hustiuc Nicoletta: Stem activities in eTwinning projects
 12:00 - 12:10 Gomes Nelson: Artificial Intelligence in the Classroom – Partner or Challenge?
 12:10 - 12:30 Holanda Leandro: Designing Culturally Sustaining Learning Environments: The Role of AI, STEAM, and Project-Based Learning
 12:30 - 12:50 Videnovik Maja: From Challenge to Opportunity: How AI and Gamification Enhance Motivation and Engagement in the Classroom
 12:50 - 13:00 Gomes Nelson: The STEAM StartUp and how we can participate in a collective library of interactive STEAM resources

Section 9: STEAM in Action – How Arts Enrich STEM Learning and Well-Being (Chair Istileulova Yelena)

- 11:00 - 11:05 Istileulova Yelena: How Arts Enrich STEM Learning and Well-Being
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 11:30 - 11:45 Kos Miha: From STEM to THE MAJESTIC: Covering Illustrations, Sonnets and Diabetes
 11:45 -12:00 Jeran Marko: Poetry from the Laboratory: Red Cabbage as a Sustainable pH Indicator and Poetry as a Teaching Tool
 12:00 - 12:15 Cizelj Boris: Silver Economy
 12:15 - 12:30 Adnyana Wayan Kun: Rethinking Ordinary Objects in Contemporary Painting Creation
 12:30 - 12:45 Pozdorovkina Irina, Rezvukhina Lidiia, Bliznyuk Elena, Zuykova Anna: Creative Wellbeing Through Plein Air Painting: A Balance between Academic Tradition and Intuition
 12:45 -13:00 Istileulova Yelena: STEAM in Action: From Atomic Structure to Well Being through Music and Digital Interpretation of Lucretius
 13:00 Plenary lecture: Papanikos Gregory: From TES (Technē, Epistēmē, Sophia) to STEAM: Bridging Ancient and Modern Conceptions of Knowledge

Editorial

With the participation of world top scientists from the fields and integration of science in international artistic production, Socratic lectures strive to present scientific and artistic excellence to the students, involve them in the creation of science and art and push forward development of curricula within university education.

14th Socratic Lectures symposium took place online on April 17, 2026.

It featured two plenary lectures, 9 scientific sessions, a poster session and the student session with about 240 active participants.

With 48 manuscripts and 11 posters received for publication, the Proceedings of the 14th Socratic Lectures is organized into four distinct sections: Part I focuses on breast cancer research, followed by medicine in Part II, physics in Part III, and interdisciplinary sciences in Part IV. This part (IV Interdisciplinary sciences) presents a meeting point for natural sciences, social sciences and arts. We are very happy that our symposia are constituted by different fields, to enrich brainstorming and ideas of the participants. Also, the Interdisciplinary science collection unites authors from Algeria, Argentina, Austria, Indonesia, Italy, Romania, Serbia, Turkey, United States of America, and Slovenia and are therefore the richest one as regards internationalization.

Part IV: front cover features an original, mid-19th-century magnetic field recording created by Michael Faraday (1791–1867) at the Royal Institution, London. By dusting fine iron filings over waxed paper placed above permanent magnets and gently warming the sheet, Faraday permanently fixed these field lines to visually map invisible natural forces. He integrated principles of chemistry and materials science—using a thermal phase transition to trap magnetic iron particles in a solidifying wax matrix. The image shows how cross-disciplinary methodologies can render abstract theoretical physics tangibly visible.

We conclude with a big thanks to all the participants who in the spirit of Socrates donated their contributions and to all those who made the events possible. Kindly invited to the next Socratic lectures.

Veronika Kralj-Iglič, Anna Romolo and Yelena Istileulova

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Review

Microplastics in Aquatic Environment: Insight from Research in Montenegro

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Abstract:

Microplastics have emerged as one of the most significant environmental pollutants of the 21st century due to their persistence, mobility, and potential ecological and human health impacts. Aquatic ecosystems are particularly vulnerable because rivers, lakes, and marine environments act both as sinks and transport pathways for plastic debris. This paper presents an overview of microplastics in aquatic ecosystems with a specific focus on Montenegro. Available investigations conducted during the last seven years indicate the presence of microplastics in freshwater systems, lake sediments, coastal sediments, fish, and shellfish. Elevated concentrations were reported in several rivers and coastal zones compared with regional literature data. The findings highlight the need for systematic monitoring, improved waste management, wastewater treatment, and stronger regulatory measures.

Keywords: Microplastics, Aquatic ecosystems, Montenegro, Sediments, Fish, Shellfish

1. Introduction

Plastic materials have become indispensable in modern society due to their durability, versatility, lightweight properties, and low production costs. Their widespread application includes packaging, construction, healthcare, agriculture, transportation, and consumer products. However, the continuous increase in plastic production, combined with inadequate waste management practices, has created a serious global environmental problem. Approximately 40% of plastic products are intended for single-use or short-term applications, particularly packaging materials, with an average lifespan of less than one month. Although recycling rates have improved in some regions, only a relatively small proportion of plastic waste is effectively recycled, while the majority accumulates in landfills or is released into the environment (Klein et al., 2015; Fischer et al., 2016).

Unlike natural materials, conventional plastics are highly resistant to biodegradation and do not readily decompose into harmless end products. Instead, they gradually fragment through physical, chemical, and biological weathering processes such as photodegradation, oxidation, hydrolysis, thermal stress, and mechanical abrasion. Over time, these processes generate progressively smaller particles known as microplastics and nanoplastics (Scherer et al., 2020).

Microplastics are commonly defined as synthetic solid polymer particles ranging from 1 μm to 5 mm in size. They exhibit substantial variability in morphology, color, density, and polymer composition. Due to their small size, persistence, and ease of transport, microplastics are now ubiquitous contaminants detected in terrestrial, freshwater, and marine environments, including remote polar regions, rivers, lakes, estuaries, coastal zones, and open oceans (Fischer et al., 2016; Hengstmann et al., 2021).

According to their origin, microplastics are generally divided into two main categories. Primary microplastics are intentionally manufactured microscopic particles used in cosmetics, personal care products, industrial abrasives, synthetic textiles, and resin pellets. Secondary microplastics arise from the fragmentation of larger plastic items such as bottles, bags, fishing gear, packaging waste, and other discarded materials. In addition to source-based classification, microplastics are frequently categorized by morphology (fibers, fragments, films, pellets, foams), particle size, color, and polymer type (Scopetani et al., 2019).

Aquatic ecosystems are among the most threatened environments with regard to plastic contamination. Rivers, lakes, transitional waters, and marine ecosystems receive continuous inputs of plastic debris from urban runoff, wastewater effluents, industrial discharges, tourism, fisheries, maritime transport, and improper waste disposal. Rivers are considered one of the principal pathways and major sources of microplastic transport from land-based environments toward lakes, estuaries, seas, and oceans (Rodrigues et al., 2018; Simon-Sánchez et al., 2019). It is estimated that nearly 80% of aquatic plastic pollution originates from terrestrial sources, while the remaining proportion is associated with marine-based activities such as shipping, aquaculture, and fisheries.

Marine environments are particularly vulnerable because floating and suspended plastic particles can be transported over long distances by currents and winds, leading to widespread contamination of coastal and offshore ecosystems. Sediments in rivers, lakes, and coastal zones act as important sinks for microplastics, where particles may accumulate over time and remain available for remobilization under changing hydrodynamic conditions (Atwood et al., 2019; Hengstmann et al., 2021).

Aquatic organisms are especially sensitive to microplastic exposure due to their constant interaction with contaminated water and sediments. Numerous studies have demonstrated the ingestion of microplastics by plankton, benthic invertebrates, mollusks, crustaceans, and fish. Once ingested, microplastics may cause physical damage, feeding disruption, reduced growth, oxidative stress, inflammation, and altered reproductive performance. Furthermore, microplastics may act as vectors for additives and adsorbed environmental contaminants, thereby increasing ecological risks and potential transfer through food webs (Digka et al., 2018; Avio et al., 2019; Gomiero et al., 2019).

The Adriatic Sea, including the Montenegrin coastal area, represents an environmentally and economically important marine region characterized by intense seasonal tourism, maritime traffic, fisheries, and coastal urbanization, all of which may contribute to plastic inputs. At the same time, Montenegro possesses diverse freshwater ecosystems, including

rivers, lakes, and reservoirs, which may also serve as recipients and transport routes for microplastic pollution (Blašković et al., 2017; Palatinus et al., 2019).

The aim of this review is to summarize and critically evaluate studies on microplastic contamination conducted in aquatic ecosystems of Montenegro over the past seven years. Particular attention is given to reported concentrations and characteristics of microplastics in river sediments, lake sediments, coastal marine sediments, as well as in mussels, shellfish, and fish collected from the Montenegrin region. In addition, this review provides a comparative analysis of concentrations recorded in Montenegro with data reported from neighboring countries and the wider regional context. Such an overview is essential for assessing the current state of microplastic pollution in Montenegro and identifying priorities for future monitoring and management strategies. Studies from Montenegro consistently demonstrate the presence of microplastics across all investigated compartments, highlighting rivers as transport pathways, lakes as accumulation zones, and coastal sediments and biota as long-term sinks, emphasizing the integrated nature of pollution dynamics in the region (Bošković et al., 2021; 2022a; 2022b; 2023a; 2023b; 2025a; 2025b; 2026a; 2026b).

2. Microplastics in aquatic environment in Montenegro

The first investigations of microplastics in Montenegro began approximately seven years ago. Since then, studies have included seven rivers, three lakes, and the Montenegrin coastal zone (sediments, fish and shellfish).

Investigated rivers include Sitnica, Ribnica, Cijevna, Zeta, Morača, Bojana, and Tara. The occurrence and characteristics of microplastics in river sediments in Montenegro, in comparison with selected European rivers, are summarized in **Table 1**. As shown in **Table 1**, microplastic concentrations in Montenegrin rivers exhibit considerable variability, with mean values generally higher than those reported for rivers in Slovenia, such as the Ljubljanica and Kamniška Bistrica. This difference may reflect variations in waste management practices, population density, and local pollution sources. However, when compared with larger European rivers such as the Rhine and Elbe, the observed concentrations fall within a comparable range, indicating that microplastic contamination is a widespread issue across Europe rather than a localized phenomenon. The dominant polymers identified in Montenegrin rivers are polyethylene (PE) and polypropylene (PP), which is consistent with their extensive use in packaging materials and consumer products. In terms of morphology, both fragments and fibers are present, with fibers often associated with domestic wastewater and textile-related sources. The relatively narrow size range (predominantly 0.5–1.0 mm) suggests ongoing fragmentation processes and potential methodological consistency across studies. Importantly, no clear relationship between river length and microplastic concentration can be observed, indicating that local anthropogenic inputs and hydrological conditions play a more significant role than river size itself. The wide concentration ranges recorded in certain rivers further point to spatial heterogeneity and the influence of site-specific factors. With respect to lake ecosystems, research has focused on lakes located within national parks of Montenegro. The analyzed lakes include Black Lake and Devil Lake, which belong to Durmitor National Park and are of glacial origin, as well as Skadar Lake, located within Skadar Lake National Park.

Table 1. Comparison of the microplastics abundance, polymer type, shape, size and color of microplastics in rivers sediment from Montenegro compared to river sediments data from the Europe (MP/100g dry sediment)

River / country	Length of the river (km)	Concentration (min-max /mean)	Polymer	Shape	Size (mm)	Color	Reference
Sitnica, Montenegro	19	7-48.7 / 28.3 ± 12.2	PP, PE	fragment, fiber	0.5-1.0	blue, red, clear	Bošković et al. 2026a
Ribnica, Montenegro	10	14.7-38.7 / 24.9 ± 8.1	PE	fragment	0.5-1.0	blue, red, clear	
Cijevna, Montenegro	56	13.7-59 / 27.3 ± 14.1	PE, PP	fragment	0.5-1.0	blue, red, clear	
Zeta, Montenegro	89	5-43 / 14.5 ± 11	PP, PE	fragment, fiber	0.5-1.0	blue, red, clear	Bošković et al. 2023b
Morača, Montenegro	113.4	2-44 / 16.9 ± 11.3	PE, PET	fiber	0.5-1.0	blue, red, clear	
Bojana, Montenegro	41	11-25 / 18 ± 5.3	PP, PE	fiber	0.5-1.0	blue, red, clear	
Tara, Montenegro	157	1-61 / 11.9 ± 11.1	PE, PP	fiber	0.1-5.0	blue, red, clear	Bošković et al. 2025a
Ljubljana, Slovenia	41	0.5-4 / 2.3 ± 2.5	PE, PP	fragment	0-0.99	colored	Matjašič et al. 2022
Kamniška Bistrica, Slovenia	33	1-3.3 / 2.2 ± 2	PE, PP	fragment	0-0.99	colored	
Ticino, Italy	248	/ 1.1 ± 0.8	EVA	/	/	/	Winkler et al. 2022
Po, Italy	652	0.05-7. /9	PE, PP	/	/	/	Atwood et al. 2019
Osa, Italy	20	/ 28.6 ± 3.7	/	fiber	/	colored	Cannas et al. 2017
Albegna, Italy	70	/ 45.3 ± 42.4	/	fiber	/	colored	
Ombrone, Italy	161	4.5-106.9 /	/	fiber	/	black, white, clear	Guerranti et al. 2017
Cecina, Italy	78	7.2-19.1 /	PVC	fragment, fiber	0.630-1.462	colored	Blašković et al. 2018
Tisza, Central Europe	1419	/ 317.7 ± 197	/	fiber	/	/	Kiss et al. 2021
Rhine, Germany	123	22.8-376.3 /	PE, PP, PS	fragment	0.630-5.0	colored	Klein et al. 2015
Main, Germany	524.9	78.6-136.8 /	PE, PP, PS	fragment	0.630-5.0	/	
Elba, Germany	1165	0.9-1596.2 / 208 ± 467	PE, PP	granule, fragment	0.126-5.0	clear	Scherer et al. 2020
Tet, France	115.8	0.7-102.9 / 25.8 ± 25.9	PE, PP	fragment, fiber	/	/	Constant et al. 2020
Ebro, Spain	930	/ 42.2 ± 11.9 / 205.2 ± 74.6	PA, PE	fiber	0.200-0.500	clear, orange	Simon-Sanchez et al. 2019
Kelvin, Great Britany	35	16.1-43.2 /	/	fiber	/	colored	Blair et al. 2019
Antuã, Portugal	38	1.8-62.9 /	PE, PP	fragment	0.055-5.0	colored	Rodrigues et al. 2018

A comparison of microplastics abundance and characteristics in lake sediments from Montenegro and other European regions is presented in **Table 2**. The data presented in **Table 2** reveal notable differences in microplastics concentrations among Montenegrin lakes, largely reflecting the degree of anthropogenic influence. Lower concentrations are observed in glacial lakes such as Black Lake and Devil Lake, which are relatively remote and less exposed to direct human activities. In contrast, Skadar Lake shows higher levels of contamination, likely due to its connection with river inflows, surrounding settlements,

and agricultural activities. When compared with European data, microplastics concentrations in Montenegrin lakes fall within the lower to moderate range. They are generally lower than heavily impacted systems such as Bizerte Lagoon in Tunisia, but comparable to values reported for lakes in Italy and Switzerland. This suggests that, while contamination is present, it is still influenced by regional environmental pressures rather than extreme pollution sources. Similar to river sediments, fibers and fragments dominate, and common polymers include PE, PP, and PET. These findings confirm that lakes act as accumulation zones, or sinks, for microplastics transported from surrounding catchments. The observed patterns highlight the importance of watershed characteristics and human activity in determining contamination levels.

Table 2. Comparison of the microplastics abundance, polymer type, shape, size and color of microplastics in lake sediment from Montenegro compared to lake sediments data from the Europe (MPs/100g dry sediment)

Lake / country	Concentration (min-max /mean)	Polymer	Shape	Size (mm)	Color	Reference
Black Lake, Montenegro	0-16 5.1 ± 1.4	PE	fragment, fiber	0.5-3	blue, red	Bošković et al. 2026b
Devil Lake, Montenegro	1-12 3.8 ± 0.5	PE, PET, PP	fragment, fiber	1-5	blue, red	
Skadar Lake, Montenegro	9-22 15.4 ± 4.3	PE, PP	fiber, fragments	1-3	blue, red, clear	Bošković et al. 2025b
Upper Balma, Italy	/ 1.75 ± 0.62	PE, PP	fiber, fragment	0.1	blue, white, black	Pastorino et al. 2023
Lower Balma, Italy	/ 1.33 ± 0.67	PE, PP	fiber, fragment	0.1	blue, white, black	
Bolosena Lake, Italy	/ 11.2 ± 3.2	/	fragment, fiber	0.3-0.5	/	Fischer et al. 2016
Chiusi Lake, Italy	/ 23.4 ± 8.5	/	fiber, fragment	0.3-0.5	/	
Lake Sassolo, Switzerland	/ 33	PE, PP	fiber	/	/	Negrete Velasco et al. 2020
Multiple lakes, Türkiye	13-121 /	PET, PP, PE	fragment, fiber,	1	/	Akdemir et al. 2025
Bizerte Lagoon, Tunisia	300-1800 796 ± 687	/	fiber, fragment	0.3-5.0	clear, white, blue	Abidli et al. 2017
Hampstead Pond no. 1, London	/ 53.9	PS, PA	fiber	0.5-1.0	blue, white, red	Turner et al. 2019
Lake Tollene, Germany	/ 141 ± 82.2	PE, PET	fragment	0.063-2 mm	/	Hengstmann et al. 2021
Vesijarvi Lake, Finland	/ 39.58 ± 9.07	PA, PS, PET	fiber, fragment	/	/	Scopetani et al. 2019

Microplastics concentrations and characteristics in marine sediments from the Montenegrin coast, in comparison with other European marine environments, are summarized in **Table 3**. As indicated in **Table 3**, the Montenegrin coastal sediments exhibit relatively high levels of microplastics contamination compared to several locations in the Adriatic Sea, particularly along the Croatian coast. However, the reported values remain lower than those observed in highly polluted regions such as parts of the Mediterranean Sea, including Tunisia. Marine sediments represent a major sink for microplastics, where particles accumulate due to hydrodynamic processes and sedimentation. The dominance of fibers and fragments in Montenegrin samples suggests a combination of sources, including wastewater discharges, textile fibers, and the degradation of larger plastic debris. The prevalence of PE and PP further supports the role of land-based plastic waste as a primary source. The semi-enclosed nature of the Adriatic Sea likely contributes to the retention and accumulation of microplastics, limiting their dispersion and enhancing local contamination. Additionally, seasonal tourism, maritime activities, and coastal urbanization represent significant pressures that may further increase microplastic inputs into the marine environment.

Table 3. Comparison of the microplastics abundance, polymer type, shape, size and color of microplastics in marine sediment from Montenegro compared to marine sediments data from the Europe (MP/kg dry sediment)

Country / Sea	Concentration (min-max /mean)	Polymer	Shape	Size (mm)	Color	Reference
Montenegro, Adriatic Sea	410.5 ± 44.7	PP, PE	fiber, fragment	1-3	blue, clear, red	Bošković et al. 2021, 2022a, 2022b
Croatia, Adriatic Sea	177.6 ± 112.6	/	fiber	1-5	clear, white, black	Blašković et al. 2017
Croatia, Adriatic Sea	310 ± 109	/	fiber, fragment	1-5	black, blue	Renzi et al. 2019
Croatia, Adriatic Sea	360 ± 169.1	PE, PP	fiber, fragment	2.5-5	clear, white, black	Palatinus et al. 2019
Croatia, Adriatic Sea	263.6 ± 64.8	PVC, PP, PA	fiber	0.5-2.5	/	Renzi & Blašković, 2020
Italy, Adriatic Sea	1445.2 ± 458.4	PE, PP	fragment	1-5	/	Vianello et al. 2013
Italy, Adriatic Sea	254.6 ± 200.4	/	fiber	2-5	clear, white, black	Renzi et al. 2018
Italy, Mediterranean Sea	272.8 ± 44	PP	fragment	0.5-1	blue, black	Piazzolla et al. 2020
Tunisia, Mediterranean Sea	7960 ± 6840	/	fiber, fragment	0.3-5	clear, white, blue	Abidli et al. 2017
Spain, Mediterranean Sea	499.1	/	fiber	0.5-2	black, blue	Alomar et al. 2016
Belgium, North Sea	166.7 ± 92.1	PS, PP, PA	fiber, granule	/	/	Claessens et al. 2011
Belgium, North Sea	585.3	/	fiber	1-3	black, clear, white	Maes et al. 2017
Holland, North Sea	224.5	/	fiber	1-3	black, clear, white	Maes et al. 2017
English, North Sea	306	/	sphere	1-3	Black, clear, white	Maes et al. 2017
France, North Sea	481.2	/	fiber	1-3	black, clear, white	Maes et al. 2017

In addition to abiotic samples, studies have also investigated the presence of microplastics in biotic components of the marine ecosystem, specifically in fish and shellfish from the Montenegrin coast. The occurrence and characteristics of microplastics in selected marine organisms from Montenegro, compared to similar species from other European regions, are presented in **Table 4**. The results summarized in **Table 4** indicate that microplastics are widely present in marine organisms from the Montenegrin coast, with relatively high average particle counts per individual and a high frequency of occurrence. In many cases, these values exceed those reported for the same species in other parts of the Adriatic and Mediterranean Seas, suggesting elevated exposure levels in the study area. Fibers are the dominant form of microplastics detected in both fish and shellfish, which is consistent with their prevalence in the surrounding environment and their origin from wastewater and textile sources. A variety of polymers, including PE, PP, PET, and others, have been identified, indicating multiple contamination pathways. The presence of microplastics in commercially important species highlights the potential for transfer through the food web and raises concerns regarding ecological and human health impacts. However, differences among studies should be interpreted with caution, as they may also reflect variations in sampling methodologies, analytical techniques, and species-specific feeding behaviors.

3. Current Challenges

Despite increasing awareness of plastic pollution and microplastics contamination, Montenegro still faces several important challenges in environmental management and pollution control. Limited institutional capacity, insufficient infrastructure, and strong seasonal pressure caused by tourism significantly complicate the implementation of effective mitigation measures.

One of the major issues is the insufficient development of systems for waste separation, recycling, and final treatment of plastic waste. Although progress has been made in municipal waste management, plastic recycling rates remain relatively low, while considerable quantities of waste are still disposed of in landfills or released into the environment. Inadequate waste collection in rural areas and along the coast further increases the probability of plastic leakage into rivers, lakes, and marine ecosystems.

Another important limitation is the restricted capacity of wastewater treatment facilities. Microplastics originating from domestic wastewater, laundry effluents, industrial discharges, urban runoff, and personal care products may enter aquatic environments through sewage systems. In the absence of advanced filtration and tertiary treatment technologies, a substantial proportion of these particles can pass through treatment plants and be discharged into rivers or coastal waters.

High consumption of single-use plastic products, including plastic bags, beverage containers, food packaging, and tourism-related disposable items, remains an additional concern. During the summer season, the population in coastal municipalities increases considerably, leading to a temporary but significant rise in waste generation and pressure on local waste management systems.

Table 4. Comparison of the microplastics abundance, frequency of microplastics occurrence, shape, and polymer type of microplastics in studied species from Montenegro compared to same species data from Europe

Species	Area	Average MP items/individual	Frequency of MP occurrence (%)	Shape	Polymer	Reference
<i>M. barbatus</i>	Montenegro, Adriatic Sea	2.9 ± 0.5	58.6	fiber, fragment	PE, PP, PET, PA	Bošković et.al. 2022b
	Italy, Adriatic Sea	1.5 ± 0.7	19.2	fiber	PE, PP	Avio et.al. 2019
	Italy, Adriatic Sea	1.0	29	fiber	/	Giani et.al. 2019
	Italy, Mediterranean Sea	1.1 ± 0.2	16.1	fiber	/	
	Greece, Mediterranean Sea	1.5 ± 0.3	32	fragment	PE, PP, PET	Digka et.al. 2018
	Turkey, Mediterranean Sea	2.1 ± 1.4	66	fiber	Nylon	Güven et.al. 2017
	Spain, Mediterranean Sea	1.9 ± 1.3	18.8	fiber	/	Bellas et.al. 2016
<i>M. merluccius</i>	Montenegro, Adriatic Sea	3.2 ± 1	54	fiber, film	PP, PE, PET, PA	Bošković et al. 2022b
	Italy, Adriatic Sea	1.6 ± 0.1	35	fiber, film	PE, PP	Avio et.al. 2019
	Italy, Adriatic Sea	1.1 ± 0.3	30.6	fiber	/	Giani et.al. 2019
	Italy, Mediterranean Sea	1.4 ± 0.5	28.2	fiber	/	
	Italy, Mediterranean Sea	/	46.3	/	/	Mancuso et.al. 2019
	Spain, Atlantic Ocean	1.0	6.7	fiber	/	Bellas et.al. 2016
<i>M. galoprovincialis</i>	Montenegro, Adriatic Sea	2.53 ± 1.1	3.3	fiber	PP, PE, PET, PA, PS, PVC, PVS	Bošković et al. 2023a
	Italy, Adriatic Sea	/		fiber, fragment	PE, PP, PET, PS, PVC	Gomiero et al., 2019
	Italy, Mediterranean Sea	3.95 ± 2.54	11.1	fiber	PE, PP, PET, PVC	Nalbone et al. 2021
	Italy, Adriatic, Ligurian and Tyrrhenian Sea	3.0 - 12.4		fiber	/	Renzi et al. 2018
	Greece, Ionian Sea	1.9 ± 0.2	6.3	fiber, fragment	PE, PP, PTFE	Digka et al. 2018
	Tunisia, Mediterranean Sea	7.7 ± 3.8	17	fiber, fragment	PE, PP, celophane	Wakkaf et al. 2020
	Spain, Mediterranean Sea	4.54 - 18.2		/	/	Capo et al. 2021
	Spain, Cantabrian Sea	2.65 ± 1.46	100	fiber	rayon, PET, PS, PE	Masia et al. 2022

A further challenge is the absence of legislation that explicitly recognizes microplastics as a specific pollutant category. While general regulations concerning waste, water protection, and marine management exist, more detailed legal frameworks are needed to regulate monitoring obligations, emission sources, industrial responsibility, and prevention strategies in line with current European environmental policies.

The lack of long-term national monitoring programs also represents a significant scientific and management gap. Most studies conducted in Montenegro have been site-specific or project-based, without continuous monitoring of trends in water, sediments, and aquatic organisms. Without harmonized methodologies and regular data collection, it remains difficult to assess temporal changes, identify hotspots, or evaluate the effectiveness of mitigation measures.

The need for coordinated regional action is particularly important because the Adriatic Sea is considered one of the more vulnerable semi-enclosed European seas regarding plastic accumulation. Its limited water exchange, intense maritime traffic, coastal urbanization, fisheries, and seasonal tourism all contribute to pollutant retention and transboundary transport. For this reason, regional cooperation among Adriatic countries is essential for effective long-term management.

4. Conclusions

Available scientific evidence clearly demonstrates that microplastics are already present in multiple aquatic ecosystems of Montenegro, including rivers, lakes, coastal sediments, as well as in fish and shellfish species of ecological and commercial importance. These findings confirm that microplastic contamination is no longer an isolated or emerging issue, but an established environmental concern affecting both freshwater and marine environments of the country. Freshwater systems, particularly rivers flowing through urbanized and industrialized areas, appear especially vulnerable because they function as major transport pathways for land-based plastic waste toward downstream lakes and the Adriatic Sea. At the same time, Montenegro's coastal zone is exposed to combined pressures from local waste sources, tourism activities, fisheries, maritime transport, and transboundary inputs carried by marine currents. Sediments in rivers, lakes, and coastal areas are of particular importance because they act as long-term sinks for microplastics and may serve as secondary contamination sources through resuspension processes. Comparisons with studies from neighboring countries indicate that several Montenegrin sites show elevated concentrations of microplastics, highlighting the need for more detailed spatial investigations and source identification. However, differences in analytical methods and sampling strategies among studies emphasize the necessity for methodological standardization in future research. Future priorities should therefore include the establishment of a harmonized national monitoring network covering water, sediments, and biota; improvement of laboratory methodologies; reduction of single-use plastics; modernization of waste collection and recycling systems; expansion of wastewater treatment capacity; stronger environmental legislation; and increased public awareness. Regional cooperation within the Adriatic basin will also be essential for addressing the transboundary nature of plastic pollution. As a country with high biodiversity, valuable freshwater resources, and an internationally recognized ecological identity, Montenegro has the opportunity to become a regional example of proactive microplastic management. By integrating scientific evidence into environmental policy, prevention strategies, and sustainable resource management, it is possible to substantially reduce future plastic contamination and protect aquatic ecosystems for the long term.

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Review

Antimicrobial Agents in Healthcare

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Abstract:

The increasing resistance of microorganisms highlights the need for new antimicrobial agents in healthcare, particularly for preventing infections on medical surfaces and implants. Promising approaches include quaternary ammonium compounds, chitosan, and graphene. Quaternary ammonium compounds are effective against a wide range of bacteria and viruses; however, their synthetic nature and environmental impact pose limitations, as well as the risk of developing resistance. Chitosan is a natural biopolymer with biocompatibility, antiviral, and antifungal properties; however, its poor solubility limits its use, necessitating chemical modifications. Graphene and its derivatives exhibit exceptional mechanical strength, large surface area, and antimicrobial activity, enabling effective prevention of biofilm formation, although their efficacy depends on specific usage conditions. Combining these materials with advanced technologies opens opportunities for developing smart, biocompatible, and environmentally friendly antimicrobial solutions that can complement or replace conventional antibiotics. Further research is essential to enhance efficacy, reduce toxicity, and increase practical applicability in clinical practice.

Keywords: Antimicrobial agents; Quaternary ammonium compounds; Chitosan; Graphene; Medical implants; Biocompatibility.

1. Introduction

The need to design new antimicrobial agents in healthcare is becoming increasingly urgent, both to prevent healthcare-associated infections and to address the growing development of bacterial resistance to existing drugs. The increasing spread of resistance to antibiotics and other antimicrobial substances poses new challenges in the treatment of infections, potentially leading to prolonged hospital stays, higher mortality rates, and increased healthcare costs (Agarwalla et al., 2019). Therefore, the development of new agents is essential for maintaining the effectiveness of therapeutic options and controlling the spread of resistance. Microorganisms that develop antibiotic resistance can spread rapidly, rendering treatments ineffective and posing a serious threat to public health. At the same time, the development of new antibiotics is slow and time-consuming, resulting in a lack of effective solutions when existing drugs fail. Consequently, there is growing interest in natural compounds, which may offer new opportunities to combat resistant bacteria. Natural products have historically played a crucial role in drug development. Over the past 40 years, more than half of newly developed antibacterial drugs have been derived from natural or semi-natural sources, while only about 22% have been purely synthetic (Confederat et al., 2021). Two broad approaches are used to create antimicrobial surfaces: prevention of microbial adhesion and contact-based inactivation. The first approach often involves superhydrophobic surfaces inspired by nature, designed to prevent microbial attachment. However, these strategies are relatively complex, mostly limited to flat surfaces, and their long-term durability remains uncertain. The second approach encompasses a wide range of contact-based inactivation strategies, all of which rely on chemical surface modification to achieve specific bactericidal and virucidal effects (Artusio et al., 2024). Bacterial species of particular interest are those capable of acquiring resistance through various mechanisms of genetic transfer, such as transformation, conjugation, transduction, and mobile genetic elements. Notable examples include *Staphylococcus aureus*, *Enterococcus* spp., *Pseudomonas aeruginosa*, members of the *Enterobacteriaceae* family, and *Acinetobacter* spp. (Confederat et al., 2021).

2. Design of Review

The review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, where applicable. A systematic literature search was carried out using PubMed, Scopus, and Web of Science, covering the period from 2007 to 2025. The search strategy included the following keywords: antimicrobial agents, quaternary ammonium compounds, chitosan, graphene, medical implants, and biocompatibility.

3. Quaternary Ammonium Compounds

Quaternary ammonium salts (QAS) are widely present in nature and play an important role in various biological processes. In addition to their natural occurrence, they are frequently synthesized chemically. Due to their diverse chemical structures and biological properties, QAS are widely used in industrial and medical applications, including disinfectants, pharmaceuticals, DNA carriers, preservatives, biocides, herbicides, and fungicides. An important aspect of their function is their ability to reduce microbial adhesion to both biotic and abiotic surfaces, thereby contributing to the eradication of biofilms formed by pathogenic microorganisms. These biofilms are often resistant to conventional drugs and disinfectants, and the use of QAS can help prevent infections and reduce the risk of disease transmission (Obłąk et al., 2021). Common disinfectants used in routine cleaning are largely based on quaternary ammonium compounds, halogens, and phenols. However, in some cases, their effectiveness against pathogenic bacteria is limited, as it depends on factors such as contact time, pH, temperature, and the type and quantity of microorganisms present (Santoro & Izzo, 2024). The chemical structure of QAS, such as alkyl chain length, the type of counterion, and the linking group, strongly influences their physicochemical properties and biological activity. For example, by integrating into microbial cell membranes, QAS can inhibit key enzymatic activities and disrupt intracellular transport, leading to reduced growth or cell death. However, their widespread use in commercial products raises concerns about the development of microbial resistance not only to QAS but also potentially to antibiotics (Obłąk et al., 2021). Polymeric surfaces containing QAC exhibit low hemolytic activity, making them suitable for safe and effective use in various

applications. These include surgical and medical implants, wound dressings, industrial equipment, water treatment systems, and food packaging, where they help reduce the risk of bacterial contamination (Santoro & Izzo, 2024). Based on structural complexity, QAC can be classified into mono-QAC (one quaternary nitrogen atom), bis-QAC (two quaternary nitrogen atoms), and poly-QAC (multiple quaternary nitrogen atoms) (Mohapatra et al., 2023; -Ortega et al., 2025). The number of quaternary nitrogen centers significantly affects antimicrobial efficacy, along with factors such as the length and nature of alkyl substituents and the presence of functional groups. It is also important to note that QAC has been detected in wastewater and sewage sludge worldwide, often at variable and sometimes high concentrations, particularly in raw sewage and industrial effluents. Although regulatory measures have reduced the levels of certain compounds, a marked increase in QAC concentrations and loads in wastewater was reported during the COVID-19 pandemic, reflecting increased disinfectant use and limited removal efficiency in treatment plants. QAC enters wastewater treatment systems via sewage networks; however, a portion can pass through treatment processes and be released into aquatic environments. It is estimated that approximately 75% of QACs enter treatment plants annually, while around 25% are directly discharged into the environment. Their removal primarily occurs through adsorption onto activated sludge, while biodegradation plays a lesser role, allowing QAC to persist and accumulate in surface waters. Concentrations in effluents and surface water typically range from below 1 to approximately 100 µg/L, while levels in raw wastewater can be significantly higher (Mohapatra et al., 2023). Environmental concerns regarding QAC arise from their potential to promote antibiotic resistance and their role as precursors in the formation of disinfection by-products. Due to slow microbial degradation and limited photolysis, these compounds can accumulate, particularly in sediments. Although detected concentrations are unlikely to pose acute risks to aquatic ecosystems, their cumulative presence may be significant in terms of resistance development and by-product formation (Pati & Arnold, 2020).

3.1. *Broad-spectrum antimicrobial activity of QAC*

The antibacterial activity of QAC is primarily based on its positive charge, which enables electrostatic interaction with negatively charged phospholipids in bacterial membranes. After initial binding, the hydrophobic alkyl chain inserts into the lipid bilayer, leading to reduced membrane fluidity, disruption of membrane integrity, impaired osmoregulation, and ultimately cell damage and death. As with antibiotics, resistance mechanisms against QAC have also developed over time. Prolonged or repeated exposure can lead to changes in membrane structure, the emergence of mutated enzymes, activation of alternative metabolic pathways, and increased expression of genes associated with biofilm formation and efflux pumps. As a result, microorganisms may develop resistance to QAC, including the ability to metabolize or degrade these disinfectants (Belter et al., 2022). The effectiveness of antibacterial activity is also influenced by material properties, particularly in polymeric surfaces. Key factors include surface charge, molecular size, hydrophilicity, and environmental conditions such as temperature and pH. Polymeric surfaces containing QAC carry a positive charge, enabling strong interactions with negatively charged bacterial cells. This negative charge originates from teichoic acids in Gram-positive bacteria and from lipopolysaccharides and phospholipids in Gram-negative bacteria, as well as from the cytoplasmic membrane. Therefore, electrostatic attraction between the surface and bacteria is a key mechanism of contact-based antimicrobial activity (Santoro & Izzo, 2024). In addition to antibacterial effects, QACs are also active against enveloped viruses, where they destabilize the lipid membrane. Cationic QAC, such as benzalkonium chlorides (BAC), can interact with the viral envelope, affecting its stability and fluidity. These changes may disrupt homeostasis, alter pH in endocytic and lysosomal vesicles, and ultimately lead to leakage, lysis, and viral inactivation (Mohapatra et al., 2023).

4. Chitosan

Although synthetic polymers offer advantages such as strength and durability, their major drawback is their non-biodegradability, which leads to long-term environmental persistence and pollution. For this reason, increasing attention has been directed toward natural, biodegradable materials. Among these, biopolymers have gained considerable interest due to their environmental compatibility and wide range of applications, including medicine, cosmetics, moisture absorption, and tissue regeneration. Chitosan is one of the most

extensively studied natural biopolymers. It is derived from the shells of marine organisms such as shrimp and crabs and possesses several advantageous properties, including biodegradability, biocompatibility, non-toxicity, non-allergenicity, affordability, and various therapeutic effects. These include antimicrobial, antitumor, antioxidant, and immunostimulatory activities. In addition, its structure can be readily modified, enabling the development of derivatives for diverse biomedical applications (Confederat et al., 2021). Chitosan exhibits antimicrobial activity against a wide range of bacteria, including both Gram-positive species (e.g., *Staphylococcus aureus*) and Gram-negative species (e.g., *Escherichia coli*), as well as other pathogens such as *Salmonella*, *Listeria*, and *Pseudomonas* (Ngo et al., 2015). However, one limitation of chitosan is its poor solubility in water, which is attributed to its rigid and crystalline structure (Xie et al., 2007). Nevertheless, the presence of amino groups allows for chemical modification, which can improve solubility and enhance antimicrobial efficacy. Modified forms of chitosan have been developed that exhibit improved solubility and higher antibacterial activity, even at neutral pH, which is particularly important for biomedical applications (Confederat et al., 2021).

4.1. Broad-spectrum antimicrobial activity of chitosan

The antibacterial activity of chitosan and its derivatives is primarily driven by electrostatic interactions. Chitosan carries a positive charge, whereas bacterial cell surfaces are negatively charged. This interaction leads to disruption of the bacterial envelope—affecting the cell wall in Gram-positive bacteria and the outer membrane in Gram-negative bacteria. As a result, membrane permeability increases, allowing essential intracellular components such as enzymes, ions, and nucleotides to leak out, ultimately leading to cell death (Confederat et al., 2021). Numerous studies over the past two decades have demonstrated that the antibacterial effectiveness of chitosan depends on multiple factors. These include intrinsic properties such as molecular weight, degree of purification, and concentration, as well as external factors such as bacterial type and age, with younger cells generally being more susceptible. Environmental conditions, including pH, temperature, and the presence of metal ions (e.g., calcium or magnesium), also significantly influence its activity (Kong et al., 2010).

In addition to antibacterial effects, chitosan also exhibits antiviral properties, which are particularly relevant in the context of difficult-to-treat viral infections such as HIV and hepatitis C. Low-molecular-weight chitosan oligosaccharides have been shown to inhibit HIV replication at non-toxic concentrations by preventing syncytium formation, reducing viral antigen (p24) production, and blocking viral entry and fusion with host cell membranes. These findings suggest potential for the development of novel antiviral therapies (Artan et al., 2010). Furthermore, chitosan-conjugated nanoparticles have demonstrated the ability to target HIV, prolong drug activity, and reduce side effects, offering potential for improved antiretroviral treatments (Ngo et al., 2015). Studies using animal models have also shown that chitosan can be effective in preventing infection with influenza A (H7N9). Rather than acting directly on the virus, chitosan appears to stimulate the host immune response, enabling a more effective defense during the early stages of infection (Zheng et al., 2016).

Chitosan also demonstrates antifungal activity, although the underlying mechanisms are not yet fully understood. It has been shown to be effective against various fungi, particularly *Candida* species, including drug-resistant strains such as those resistant to fluconazole. Its activity depends on factors such as molecular weight, degree of deacetylation, concentration, and pH, with optimal effects observed at lower pH and concentrations between 1–5%. Chitosan disrupts fungal cell membranes, increases membrane permeability, causes the loss of essential ions (e.g., potassium), and inhibits respiration and metabolism. Some studies have also reported synergistic effects when chitosan is combined with antifungal drugs such as fluconazole, although this effect depends on the specific type of chitosan and drug used (Confederat et al., 2021).

5. Graphene

Graphene is one of the most promising materials in modern science. Due to its exceptional mechanical strength, large surface area, excellent thermal and electrical properties, and capacity for chemical modification, it has attracted significant attention, particularly in biomedical applications. Research over recent decades has demonstrated that graphene is not only versatile and robust but also biocompatible, antibacterial, and corrosion-resistant,

which is particularly important for medical implants and dental materials. Despite extensive research, the application of graphene coatings in dentistry and implantable medical devices remains limited, indicating substantial potential for future development (Srimaneepong et al., 2022). Graphene-based materials exhibit strong antibacterial properties, effectively inhibiting bacterial growth and proliferation. When applied as coatings on titanium, a commonly used implant material, they can significantly reduce biofilm formation and enhance resistance to microbial infections. In one study, graphene coatings reduced biofilm formation by bacteria such as *Pseudomonas aeruginosa*, *Enterococcus faecalis*, *Streptococcus mutans*, as well as fungi such as *Candida albicans*, by approximately 50% after only two applications. This effect has been attributed to the hydrophobic nature of graphene, which limits bacterial adhesion to surfaces (Agarwalla et al., 2019). Graphene derivatives, particularly graphene oxide (GO) and reduced graphene oxide (rGO), are highly effective antimicrobial materials that act against a wide range of bacteria and fungi. Their activity is mainly associated with the induction of oxidative stress and damage to the cell membrane. Although their effectiveness depends on material properties and the type of microorganism, they generally exhibit strong and broad-spectrum antimicrobial activity (Pandit et al., 2021). Graphene and its derivatives are typically more effective against Gram-positive bacteria, which is related to differences in cell wall structure. Gram-negative bacteria possess an additional outer membrane rich in lipopolysaccharides, providing increased protection against external stress. Furthermore, graphene-based materials show significant potential against antibiotic-resistant bacteria, making them promising candidates for future medical applications (Mohammed et al., 2020).

5.1. Antimicrobial Activity of graphene

The antimicrobial activity of graphene and its derivatives can be explained by several interconnected mechanisms. A key factor is mechanical damage, as the sharp edges of graphene sheets can disrupt bacterial membranes, leading to loss of integrity and leakage of intracellular contents. Another important mechanism is the induction of oxidative stress, either through the generation of reactive oxygen species (ROS) or via ROS-independent pathways, which disrupt essential cellular functions and lead to cell death. In addition, graphene sheets can physically wrap around and trap bacterial cells, isolating them from their environment, limiting nutrient availability, and preventing proliferation. This trapping effect further enhances membrane damage and contributes to the overall antimicrobial activity (Mohammed et al., 2020; Pandit et al., 2021).

6. Conclusions

Quaternary ammonium compounds are highly effective antimicrobial agents, making them a popular choice in many applications. However, their synthetic nature may pose environmental concerns, and the potential development of microbial resistance limits their long-term use. In contrast, chitosan, as a natural material, offers important advantages in terms of biocompatibility and environmental sustainability. Its antiviral properties further enhance its potential for applications in medicine and pharmaceuticals. Nevertheless, its limited solubility represents a practical challenge, often requiring modification or combination with other materials to achieve optimal performance.

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Research

Biological Effects of Plant Cannabinoids on *Saccharomyces cerevisiae* Assessed Using the Kirby-Bauer Disk Diffusion Method

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Abstract:

Cannabis sativa L. subsp. *sativa*, commonly known as hemp, has historically been used for its nutritional, industrial, and medicinal properties. The plant produces cannabinoids such as cannabidiol (CBD), which have shown therapeutic effects, including anti-inflammatory, anxiolytic, and analgesic properties. This study examines the antimicrobial potential of CBD and a complete hemp isolate against *Saccharomyces cerevisiae*, a model yeast organism. Using the solid-state diffusion method, different concentrations of CBD and hemp isolate were applied to *S. cerevisiae* cultures. Results showed that both CBD and hemp isolate displayed varying levels of antimicrobial activity, with the most significant effects observed at higher concentrations (500 µg/mL) after 24 hours of exposure. The study suggests that cannabinoids may provide promising natural antifungal agents for further research and application in biotechnology and pharmaceuticals.

Key words: Cannabinoids; CBD; *Cannabis sativa* L. subsp. *sativa*; *Saccharomyces cerevisiae*; Disk diffusion test; Antifungal activity

1. Introduction

1.1. *Cannabis sativa* L. subsp. *sativa*

Cannabis sativa L. subsp. *sativa* (common hemp) is an annual dioecious plant belonging to the Cannabaceae family. Historically, it has been cultivated extensively for its nutritional, industrial, and medicinal value. Hemp is found across all latitudes due to its high phenotypic adaptability. Morphologically, the leaves are characteristically palmate, comprising five to nine narrow, serrated, and dark green leaflets. The first pair of leaves usually contains a single leaflet, with the number gradually increasing to a maximum of thirteen leaflets per leaf (most commonly seven or nine), depending on the variety and growing conditions (Pečan et al., 2021). During the transition to the reproductive phase, the leaflet numbers decrease, often reducing to a single leaflet near the apical inflorescences. The stem is typically erect, slender, and highly fibrous, capable of reaching several meters in height (Pečan et al., 2021; Mišič Jančar et al., 2024).

The flowers of the female plant are arranged in inflorescences and can produce hundreds of seeds rich in oils that are used for food purposes. The stems, leaves, and flowers of hemp are covered with glandular hairs known as trichomes, which are particularly concentrated in certain parts of the female inflorescence. Trichomes are specialized epidermal appendages that are the primary biosynthetic sites for secondary metabolites, notably phytocannabinoids and volatile organic compounds such as terpenes and terpenoids. Collectively, these lipophilic compounds constitute the hemp resin and confer the plant's characteristic aroma (Tavčar Benković et al., 2019).

1.2. Cannabinoids

Phytocannabinoids represent a structurally diverse class of lipophilic, terpenophenolic compounds naturally synthesized as secondary metabolites in plants of the *Cannabis* and *Humulus* genera. To date, over 120 distinct phytocannabinoids have been isolated and identified from *C. sativa* (Morales et al., 2017). Emerging pharmacological research indicates that terpenophenolic compounds exhibit protective effects against inflammation and apoptosis in the cardiovascular system (Abdul Ghani et al., 2023). The most abundant pharmacologically active compounds in cannabis are the cannabinoids cannabidiol (CBD) and Δ^9 -tetrahydrocannabinol (THC), which are recognized as medicinal agents (Tavčar Benković et al., 2019; Mišič Jančar et al., 2024).

Δ^9 -Tetrahydrocannabinol (THC) is a highly lipophilic, glassy solid at room temperature, readily soluble in alcohols, hydrocarbons, and lipids. As the principal psychoactive constituent of cannabis, its regulatory status restricts general use. As a narcotic, it is classified as a Schedule III substance under the Controlled Substances Act (CSA), allowing its use for medical and research purposes. However, targeted formulations are utilized clinically for the management of specific medical conditions. These include spasticity associated with multiple sclerosis, refractory chemotherapy-induced nausea and vomiting, glaucoma, pain associated with AIDS, epileptic seizures, and chronic pain syndromes (Tavčar Benković et al., 2019; Whiting et al., 2015).

Cannabidiol (CBD) is the second most active constituent of *C. sativa* and was first isolated in 1940 (Tavčar Benković et al., 2019). At room temperature, CBD is a colourless, white, or yellow crystalline solid with a boiling point of 175 °C. Under specific conditions, such as exposure to strong acids or high temperatures, trace amounts of CBD may undergo cyclization to Δ^9 -tetrahydrocannabinol (THC) (Tavčar Benković et al., 2019). While trace amounts of CBD have been shown to undergo *in vitro* cyclization to form THC under extreme conditions, whether this conversion actually occurs *in vivo* is a subject of significant controversy within the scientific literature (Golombek et al., 2020). CBD is a widely used ingredient in dietary supplements and cosmetic products. The European Commission has included CBD in the list of permitted cosmetic ingredients, where it is used as an antioxidant, skin-protecting, and emollient agent. Unlike THC, CBD is non-psychoactive. Preclinical and clinical evidence indicate that CBD may help alleviate anxiety and insomnia and reduce inflammation associated with arthritis. Natural cannabinoids, including CBD, have shown positive effects in the treatment of various skin diseases. CBD has been reported to reduce cravings for tobacco, heroin, and certain other addictive substances (Hurd et al., 2019; Pellati et al., 2018; Grinspoon, 2024).

Both CBD and THC (**Figure 1**) interact with the endocannabinoid system in the human body; however, they differ in their mechanisms of action and receptor affinity. THC has a strong effect on CB1 receptors in the brain, which is reflected in behavioural changes. Such effects are not expected for CBD, as it acts on different receptors within the endocannabinoid system (e.g., 5-HT1A, TRPV1), contributing to its broad therapeutic profile without inducing intoxication (Pertwee, 2008).

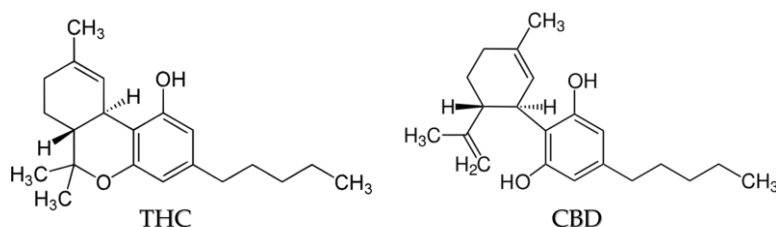


Figure 1. Structures of tetrahydrocannabinol (THC) and cannabidiol (CBD).

1.3. Medical applications

Extracts from Indian hemp (*Cannabis sativa* subsp. *indica*) and industrial hemp have been used in traditional medicine for thousands of years. In the 19th century, preparations used for pain relief and the prevention of cough and nausea—particularly in the United States and England—contained extracts from the female inflorescences of Indian hemp. It was used for their analgesic, antiemetic, and antitussive properties (Zuardi, 2006).

When hemp extracts were classified as prohibited substances in 1942, research on the medicinal use of extracts and cannabinoids came to a halt. The research of cannabinoid science resumed in the late 1980s and early 1990s with the discovery of the human endocannabinoid system, which provided a mechanistic rationale for the plant's physiological effects (Mechoulam & Parker, 2013). In 2016, the first medicinal product containing natural Δ^9 -tetrahydrocannabinol (THC) and cannabidiol (CBD) was approved for the treatment of multiple sclerosis. A medicinal product containing a natural CBD extract for the reduction of epileptic seizures is also available on the market, and additional drugs are being developed to alleviate pain and stimulate appetite in cancer patients and individuals infected with HIV. The effects of cannabinoids on Parkinson's and Alzheimer's diseases are also under investigation (Tavčar Benković et al., 2019).

In addition to their medical applications, cannabinoids play an active role in protecting plants against microbial infections. Emerging *in vitro* and *in vivo* research has highlighted the potent antimicrobial—and particularly antibacterial—efficacy of cannabinoids against multi-drug resistant bacterial strains (e.g., MRSA) and various fungal pathogens, presenting a novel approach for antimicrobial drug discovery (Karas et al., 2020, Bahraminia, 2025; Pečan et al., 2023).

Despite cannabis significant therapeutic potential, there are still numerous negative effects. The clinical application of cannabis and isolated cannabinoids is complicated by a well-documented adverse event profile. Chronic consumption carries a risk of developing cannabis addiction and dependence, particularly due to chronic consumption of the THC molecule. Acute and chronic adverse effects also include: increased heart rate, impaired coordination, fatigue, deterioration of short-term memory, and the potential exacerbation of psychiatric sequelae, such as anxiety, paranoia, and in vulnerable individuals, psychosis (Volkow et al., 2014; Tavčar Benković et al., 2019).

CBD is increasingly used in veterinary medicine for its potential therapeutic effects, including pain management, anxiety reduction, and anti-inflammatory properties. Its non-psychoactive nature makes it a safe alternative to traditional medications for treating various conditions in animals. Additionally, CBD has shown promise in supporting the overall well-being of pets, especially in managing chronic conditions such as arthritis and epilepsy (Schofs et al., 2026).

1.4. *Saccharomyces cerevisiae*

S. cerevisiae is a single-celled, facultatively anaerobic microorganism belonging to the fungal kingdom, with oval or spherical cells (Que et al., 2024). On solid culture media, *S. cerevisiae* forms milky-white, convex colonies with moist, shiny surfaces (Que et al., 2024).

Under aerobic conditions, it converts sugars into CO₂ and energy, while under anaerobic conditions, it converts sugars into ethanol, CO₂, and glycerol through alcoholic fermentation (Bušič et al., 2018). *S. cerevisiae* is widely used in scientific research and is considered a model organism in genetics, cell biology, biotechnology, and molecular biology. Its value as a model organism lies in its affordability and small genome, which was completely sequenced in 1996 and is recognised as the first fully sequenced eukaryotic genome (Goffeau et al., 1996).

Despite its fungal properties, it also shares similarities with human cells, particularly in cellular processes such as the cell cycle, transcription, and DNA replication. Approximately 23% of *S. cerevisiae* genes are homologous to the human genome (Liu et al., 2017). It reproduces rapidly, dividing every 90 minutes under optimal conditions (Vanderwaeren, 2022). Such microorganisms are usually cultivated on simple nutrient media and are not considered ethically controversial model organisms, unlike animal models such as mice or rats. In biotechnology, *S. cerevisiae* is widely used as a model for studying metabolic pathways, including fermentation and respiration, and plays an important role in drug development, particularly in insulin production (Karathia et al., 2011; Seyidoglu & Aydin, 2020). Yeast has also been used to study the cell cycle, DNA repair, and other cellular mechanisms. Furthermore, it serves as a model for studying cell cycle mutations associated with cancer and certain diseases, especially neurodegenerative disorders (Galao et al., 2007).

Fungi can be beneficial to humans, but they can also be harmful and cause numerous problems, such as mould growth on walls and plants, skin and systemic mycoses, and candidiasis in humans and animals. Due to the excessive use of conventional antimicrobial drugs, resistance to antimycotics is becoming an increasing problem, highlighting the urgent need for new alternatives and the development of strategies to prevent and control microbial diseases in humans, animals, and plants, as well as food contamination (Coelho, 2025). In modern biomedical and pharmaceutical research, the use of plant secondary metabolites is becoming increasingly important (Baričević, 1996). Several studies have shown that cannabinoids, alone or in combination with conventional antibiotics, have an antimicrobial effect on Gram-positive and Gram-negative bacteria and an antifungal effect on yeasts and phytopathogenic fungi (Ali et al., 2012).

This study investigates the effects of plant-derived CBD and a complete isolate of common hemp (*Cannabis sativa* L. subsp. *sativa*) on the growth and reproduction of yeast (*S. cerevisiae*) using the solid-state diffusion method. The results may be important for developing natural antifungal agents with potential applications in various fields beneficial to humans.

2. Materials and Methods

2.1. Experimental suspensions of plant material and Kirby–Bauer disk diffusion method

Plate Count Agar (PCA) solid medium was prepared as follows: 300 mL of deionised water was measured into a 500 mL Erlenmeyer flask, and 6.75 g of dehydrated agarose mixture for PCA (Vegitone, Millipore) solid medium was dissolved in it. With vigorous stirring, the medium base was completely dissolved and heated until a clear solution formed. The prepared mixture was removed from the heat and cooled to approximately 60 °C. To prevent contamination, the rim of the Erlenmeyer flask was quickly sterilised by passing it through a flame, and the mixture was poured into prepared Petri dishes, filling each to about two-thirds of their volume. Once cooled and solidified, the media were labelled and stored in an incubator for further use.

In the experiment, samples of pure CBD and cannabinoid full-spectrum isolate were used, as reported by Juteršek et al. (2025), and characterized by Fourier transform infrared (FTIR) spectroscopy. FTIR analysis shows that the full-spectrum isolate contains CBD and other non-psychoactive cannabinoids with similar structural features. The absence of distinct additional peaks indicates a lack of unrelated impurities, and the spectra confirm the chemical relatedness of the two samples. The CBD sample was a white powder with 99.3% purity. The full-spectrum isolate, free of psychoactive components such as THC, was partially crystalline and amber colored. Both samples were donated by Herbana Ltd.

50.0 mg of the active ingredient CBD was carefully weighed into a 50 mL Falcon tube, while 50 mg of a complete hemp isolate, containing a mixture of various cannabinoids (primarily CBD) and other natural compounds, was weighed into a second 50 mL Falcon

tube. The isolate is a partially crystalline, amber-coloured mixture. To each sample, 0.5 mL of DMSO (Merck, Germany) was added as a co-solvent. The volumes were adjusted to 50 mL with deionised water, and the mixtures were homogenised at 35 °C for 10 minutes in an ultrasonic bath (Elmasonic P, Germany). General suspensions of different concentrations were then prepared. In 10 mL Falcon tubes, suspensions with concentrations of 10, 50, 100, and 500 µg/mL of the cannabinoid isolate and CBD were prepared. Again, 0.1% DMSO was added as a co-solvent, and the mixtures were homogenised at 35 °C in an ultrasonic bath for 10 minutes. The *S. cerevisiae* suspension was prepared by suspending 100 mg of dry baker's yeast (Fala, Slovenia) in 50 mL of saline solution. A confluent *S. cerevisiae* smear was aseptically applied to the prepared culture media using a cotton swab, and three discs were placed on each plate. Precisely 10 µL of each prepared suspension was applied to the discs (*diameter* = 0.5 mm, quantitative filter paper MN 640W, Macherey-Nagel, Germany), with the procedure repeated three times per sample. Control samples consisted of 10% hydrogen peroxide (Merck, Germany) and saline solution (B. Braun, Germany).

The culture samples prepared as described were incubated in a Heratherm IGS60 GP incubator at 37 °C and evaluated after 24, 48, and 72 hours. Antimicrobial activity was assessed by measuring the diameter of the inhibition zones, defined as the clear areas surrounding the filter discs where microbial growth was absent. Each concentration of the cannabinoid samples was tested in triplicate against the model *S. cerevisiae* to ensure reproducibility and statistical reliability of the results.

3. Results

The experimental results were statistically analysed based on three parallel determinations and expressed as the diameter of the growth inhibition zone of the model organism. Both the concentration of the applied cannabinoid and the exposure time influenced the size of the inhibition zone. The first effects of the active ingredient CBD and the complete cannabinoid isolate on the model organism were observed after 24 hours of exposure. The control samples (**Table 1**) showed the expected results. As expected, the largest inhibition zone was observed with the positive control, 10% hydrogen peroxide, and the smallest with the physiological solution.

Table 1. The results of the inhibition zones for individual samples, taking into account the measurement error.

		Inhibition zone diameter [cm]		
		<i>S. cerevisiae</i>		
No.	Sample	24 h	48 h	72 h
1	10 µg/mL CBD	0.9 ± 0.2	0.9 ± 0.1	0.9 ± 0.2
2	50 µg/mL CBD	0.9 ± 0.2	1.4 ± 0.6	1.1 ± 0.3
3	100 µg/mL CBD	1.1 ± 0.8	1.2 ± 0.3	1.3 ± 0.6
4	500 µg/mL CBD	8.6 ± 0.2	8.6 ± 0.1	2.2 ± 0.2
5	General CBD suspension	0.9 ± 0.1	1.1 ± 0.2	0.9 ± 0.1
6	10 µg/mL isolate	0.6 ± 0.1	1.0 ± 0.3	0.9 ± 0.1
7	50 µg/mL isolate	0.8 ± 0.1	2.1 ± 0.4	1.3 ± 0.4
8	100 µg/mL isolate	0.7 ± 0.1	0.9 ± 0.1	0.6 ± 0.0
9	500 µg/mL isolate	0.8 ± 0.1	1.3 ± 0.3	0.9 ± 0.2
10	General isolate suspension	0.9 ± 0.5	1.1 ± 0.2	0.8 ± 0.1
11	Saline solution	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
12	10% H ₂ O ₂	8.6 ± 0.0	8.6 ± 0.0	8.6 ± 0.0
13	0.1% DMSO	0.6 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

4. Discussion and Conclusion

When examining the effect of the active ingredient CBD (**Table 1**), the most effective concentration was 500 µg/mL, which produced the greatest effect within 24 hours, followed by 50 µg/mL. The size of the inhibition zone increased linearly for up to 48 hours at both concentrations, then began to decrease. At 100 µg/mL, a constant increase in the inhibition zone was observed, indicating that this concentration also had an effect. The lowest measured concentration of cannabidiol, 10 µg/mL, had no significant effect on yeast between 24 and 72 hours.

Applications of different concentrations of the cannabis isolate showed varying effects (**Table 1**). Within the first 24 hours, the 500 and 50 µg/mL concentrations had a similar impact. After 72 hours, the lowest effect was observed at 100 µg/mL, with the inhibition zone of the model organism measuring 0.6 cm. At all concentrations, the effect of the cannabis isolate increased during the first 48 hours and then decreased over 72 hours. Based on yeast growth, it can be concluded that their abundance decreased in the first 48 hours under the influence of the isolate. For further applications, this information is crucial, as it allows determination of how long the tested substance remains effective and when its effect is nullified.

The observed results show that pure CBD demonstrated greater antimicrobial activity than the full-spectrum isolate. This is notable, as one might expect a synergistic effect between CBD and other cannabinoids or compounds present in the isolate. One possible explanation is the presence of inhibitory interactions within the full-spectrum mixture. However, a more likely interpretation involves physicochemical properties, particularly solubility and diffusion capacity (Hoover & Harlander, 1993; Bonev et al., 2008). Pure CBD is more soluble and diffusible than the heterogeneous mixture in the full-spectrum isolate. In antimicrobial diffusion assays, the size of the inhibition zone is strongly influenced by a compound's ability to diffuse through the medium, which depends on molecular weight and structural complexity (Hoover & Harlander, 1993; Bonev et al., 2008). The full-spectrum isolate is a mixture of multiple compounds that may collectively have a higher average molecular weight and reduced mobility compared to pure CBD. Therefore, pure CBD may diffuse more efficiently through the medium, resulting in a larger inhibition zone and an apparent increase in antimicrobial activity.

Similar studies using the diffusion method of active substances onto a solid medium have also been conducted by other research groups. By studying an extract from *Cannabis sativa* seeds, Ali et al. (2012) demonstrated weak activity against the fungi *Aspergillus niger* and *Candida albicans*. Later, Kesavan et al. (2024) confirmed the antifungal activity of cannabidiol against *C. albicans* and *Malassezia furfur*. Schofs et al. (2021) also reported successful antifungal activity, while Al Ubeed et al. (2023) did not demonstrate an effect of cannabinoids on fungi.

In the context of antibacterial activity, lower concentrations exhibited greater activity. This is attributed to the solubility and stability of suspensions and the resulting bioavailability of the tested active substances. The size of the growth inhibition zone of the model organism was influenced by the concentration of the applied cannabinoid and the duration of exposure. It is confirmed that the effect of common hemp isolates on the model organism *S. cerevisiae* can be studied using various methods and techniques. The results of this research can be used to develop new strategies and inform further applications.

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Conflicts of Interest: The authors declare no conflict of interest.

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Review

Bisphenol Exposure from Clear Orthodontic Aligners: A Systematic Review of Experimental and Clinical Evidence

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Abstract:

Clear orthodontic aligners have become widely adopted in contemporary orthodontic practice; however, concerns persist regarding the potential release of bisphenols from polymer-based materials and their biological effects. This study systematically reviewed the available evidence on bisphenol release from clear aligners, integrating findings from systematic reviews, in vitro investigations, and clinical studies.

The literature consistently demonstrated substantial heterogeneity in study design, analytical methods, and outcome reporting. Most in vitro studies reported minimal or undetectable bisphenol A (BPA) release under simulated oral conditions, although isolated investigations identified low levels of leaching, primarily during the initial phase of material exposure. In contrast, clinical studies revealed transient increases in salivary BPA concentrations following aligner placement or attachment procedures, with levels typically returning to baseline within a few days.

Emerging evidence also suggests the potential release of alternative compounds, including bisphenol analogues and plasticizers, which may contribute to the overall biological profile of these materials. Despite generally low measured concentrations, the cumulative effects of long-term exposure, particularly in younger populations undergoing prolonged orthodontic treatment, remain insufficiently understood.

Overall, current evidence indicates that bisphenol exposure associated with clear aligners is limited and predominantly transient. However, the lack of standardized methodologies and long-term clinical data precludes definitive conclusions regarding their long-term biocompatibility and safety. Future studies should prioritize longitudinal designs, standardized analytical protocols, and comprehensive toxicological assessments.

Keywords: Bisphenol A; Clear aligners; Orthodontic biomaterials; Biocompatibility; Endocrine disruption

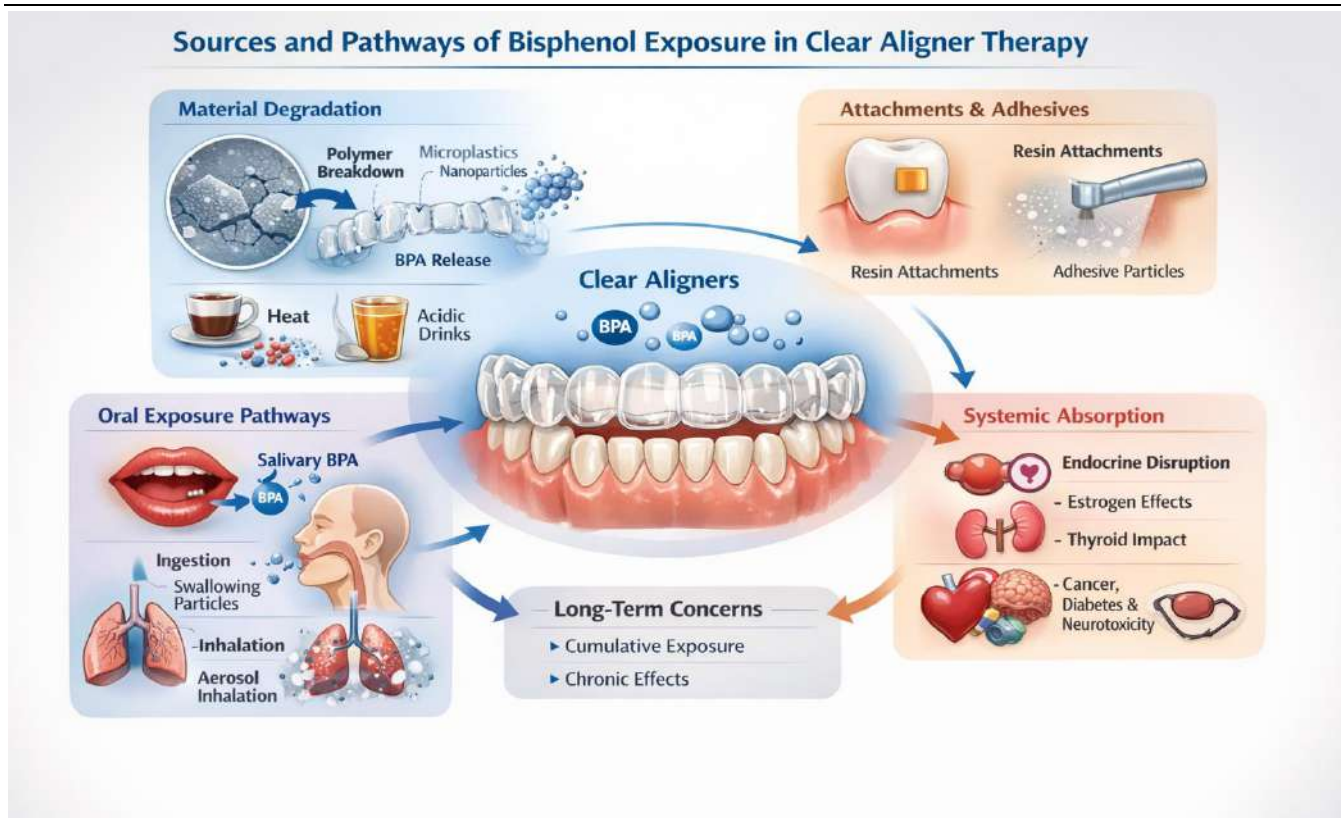


Figure 1. Graphical abstract of bisphenol exposure from clear aligners. (Figure created by authors' instructions with the help of ChatGPT)

Clear thermoplastic aligners and composite attachments represent potential sources of bisphenol release (BPA, BPF, BPS) into the oral environment. Exposure pathways include direct salivary contact, inhalation of aerosols generated during attachment removal, and microabrasion resulting from repeated insertion and removal of aligners. Evidence from *in vitro* and clinical studies suggests that bisphenol release is generally low and primarily transient, occurring during the initial phase of material use. Despite low detected concentrations, potential biological effects include endocrine disruption and systemic responses, highlighting the need for further long-term investigation.

1. Introduction

Bisphenol A (BPA) is a synthetic monomer widely used in the production of polymer-based dental materials, including thermoplastic orthodontic aligners. As a precursor of bisphenol A glycidyl methacrylate (Bis-GMA), BPA is a fundamental component of many resin-based systems used in orthodontics and restorative dentistry (Eliades, 2017). Beyond its industrial relevance, BPA has attracted considerable scientific attention due to its endocrine-disrupting properties and its ability to interfere with oestrogenic, androgenic, and thyroid hormone signalling pathways (Fonseca et al., 2022; Teng et al., 2013; Moriyama et al., 2002). These interactions have been associated with metabolic dysregulation, cardiovascular effects, and potential carcinogenic outcomes (Gao et al., 2015; Maniradhan & Calivarathan, 2023).

The increasing adoption of clear aligner therapy has intensified concerns regarding chronic low-dose exposure to bisphenols released from intraoral polymeric devices. Unlike conventional orthodontic appliances, aligners are worn for extended periods, creating conditions that may promote material ageing, mechanical wear, and chemical leaching (Iliadi et al., 2020). In addition, composite attachments, routinely used to enhance treatment efficiency, may represent an additional source of monomer release, particularly during placement and removal procedures involving mechanical abrasion and aerosol generation.

To address safety concerns, alternative bisphenol analogues such as bisphenol F (BPF) and bisphenol S (BPS) have been introduced. However, emerging evidence suggests that these compounds may exhibit biological activity comparable to BPA, raising concerns regarding their long-term safety (Fonseca et al., 2022). Therefore, a comprehensive evaluation of bisphenol release from clear aligners and its biological relevance is essential.

2. Materials and Methods

This systematic review was conducted in accordance with the PRISMA 2020 guidelines to ensure transparent and reproducible reporting.

2.1 Search Strategy

A comprehensive literature search was performed in the electronic databases PubMed, Scopus, and Web of Science. Google Scholar was used as a supplementary source to identify additional relevant studies. The search covered publications from January 2010 to December 2025.

The following keywords and Boolean combinations were used: ("bisphenol A" OR "BPA" OR "bisphenol F" OR "BPF" OR "bisphenol S" OR "BPS") AND ("clear aligners" OR "thermoplastic orthodontic appliances" OR "orthodontic retainers") AND ("release" OR "leaching" OR "exposure")

2.2 Eligibility Criteria

Studies were included if they met the following criteria:

- original research articles or systematic reviews
- in vitro, in vivo, or clinical studies
- focused on bisphenol release from clear aligners or thermoplastic orthodontic appliances
- published in English

Exclusion criteria were:

- studies on conventional orthodontic appliances without thermoplastic materials
- conference abstracts without full text
- editorials, opinions, or non-peer-reviewed content

2.3 Study Selection

All identified records were imported into a reference management system, and duplicates were removed. Two independent reviewers screened titles and abstracts for relevance. Full-text articles were assessed for eligibility, and disagreements were resolved by consensus.

2.4 Data Extraction

Data were extracted using a standardized form, including:

- study type
- material investigated
- experimental or clinical conditions
- analytical method
- detection of bisphenols
- key findings

2.5 Risk of Bias Assessment

Due to the heterogeneity of included study designs, a formal meta-analysis was not performed. The risk of bias was qualitatively assessed based on study design, sample size, analytical sensitivity, and reproducibility of methods.

The diagram (**Figure 2**) summarizes the identification, screening, eligibility assessment, and inclusion of studies in this systematic review, conducted in accordance with PRISMA 2020 guidelines. A total of 320 records were identified through database searching and additional sources. After removal of duplicates, 266 records were screened, of which 246 were excluded based on title and abstract. Twenty full-text articles were assessed for eligibility, and 12 were excluded due to irrelevance to the research question, insufficient data, or use of non-thermoplastic materials. Ultimately, eight studies were included in the qualitative synthesis.

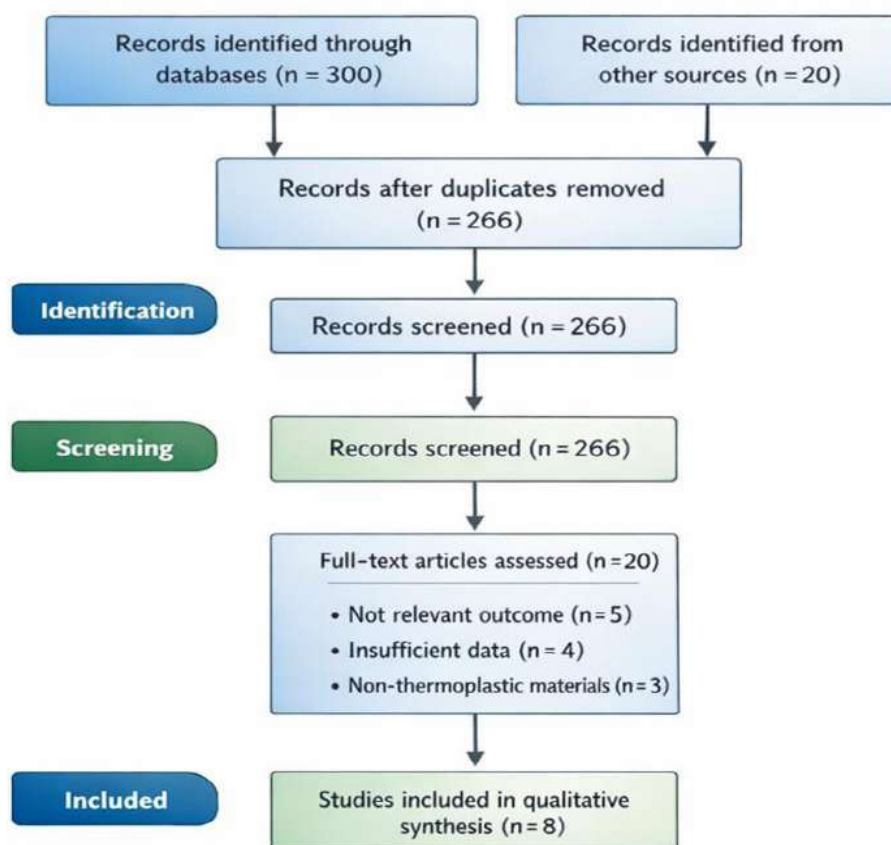


Figure 2. PRISMA 2020 flow diagram illustrating the study selection process. No automation tools were used during screening.

Table 1. Overview of included studies investigating bisphenol release from clear orthodontic aligners.

Study	Type	Material	Method	BPA detected	Key findings
Iliadi et al., 2020	Systematic review	Various aligners	Multiple	Minimal	Low-quality evidence, high heterogeneity
Peter et al., 2023	Systematic review	Thermoplastic aligners	Multiple	Mostly no	Majority in vitro, inconsistent results
Yazdi et al., 2023	Systematic review	Aligners and retainers	HPLC, LC-MS	Variable	Limited clinical evidence
Kotyk & Wiltshire, 2014	In vitro	Retainer adhesive	HPLC	Yes	BPA release only first 3 days
Milling et al., 2025	In vitro	Multiple aligners	GC-MS	No	No BPA, but DEP detected
Arslan Avan et al., 2025	In vitro	Invisalign®, and Essix ACE®	LC-MS/MS	No	No detectable BPA
Vitores-Calero et al., 2025	Clinical	Invisalign®	LC-MS	Yes (transient)	Increase after 30 min, baseline after 7 days
Azhagudurai et al., 2024	Clinical	Multiple aligners	LC-MS	Yes (early)	BPA only first 24 h

Table 1 summarizes study characteristics, including study design (systematic review, in vitro, or clinical), material type, analytical methods, and reported bisphenol detection. The included studies demonstrate substantial methodological heterogeneity and variability in analytical sensitivity, which limits direct comparison of quantitative outcomes across studies.

3. Results

The included studies demonstrated substantial heterogeneity in experimental design, analytical sensitivity, and reporting, precluding direct quantitative comparison. Most in vitro studies reported negligible or undetectable BPA release, particularly when analysed using high-sensitivity techniques such as LC–MS/MS. However, several studies identified low-level release during the initial exposure period, likely reflecting residual monomers or early-stage material degradation (Kotyk & Wiltshire, 2014). Clinical studies consistently demonstrated transient increases in salivary BPA concentrations shortly after aligner placement or attachment procedures, with levels returning to baseline within days (Vitores-Calero et al., 2025; Azhagudurai et al., 2024). These findings indicate that exposure is primarily confined to the early phase of treatment. Importantly, several studies reported the presence of alternative compounds, including plasticisers such as diethyl phthalate, even in the absence of detectable BPA (Milling et al., 2025), suggesting that BPA alone may not adequately represent the chemical exposure profile of these materials.

4. Discussion

The findings of this review indicate that bisphenol release from clear aligners is generally low and predominantly transient. This is consistent with previous systematic reviews reporting minimal or undetectable BPA release in most in vitro studies (Iliadi et al., 2020; Peter et al., 2023; Yazdi et al., 2023). Nevertheless, measurable release during the initial exposure phase has been observed and is most likely attributable to residual monomers and early-stage polymer degradation. Clinical evidence provides a more relevant representation of real exposure conditions, demonstrating short-term increases in salivary BPA levels following aligner placement (Vitores-Calero et al., 2025; Azhagudurai et al., 2024). These transient patterns suggest that early material ageing and surface interactions, rather than continuous degradation, are the primary determinants of exposure. However, the detection of alternative leachable compounds highlights an important limitation of current research, as the absence of BPA does not imply chemical inertness. Furthermore, the biological relevance of chronic low-dose exposure remains uncertain, particularly in light of non-monotonic dose–response relationships characteristic of endocrine-disrupting compounds (Teng et al., 2013; Fonseca et al., 2022). The variability between in vitro and clinical findings reflects differences in experimental conditions and underscores the need for standardised methodologies. Future research should prioritise longitudinal clinical studies integrating advanced analytical techniques and clinically relevant exposure models. Taken together, current evidence suggests that bisphenol exposure from clear aligners is limited and predominantly transient; however, its long-term biological significance remains insufficiently defined.

5. Conclusions

Although bisphenol release from clear orthodontic aligners is generally minimal and transient, its long-term biological relevance remains insufficiently understood due to methodological heterogeneity and the absence of longitudinal evidence. Future studies should focus on standardised clinical protocols and comprehensive assessment of both bisphenols and alternative leachable compounds to establish the long-term safety of thermoplastic orthodontic materials.

Conflicts of Interest: The authors declare no conflict of interest.

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Research

Extracellular Vesicles in the Udder Fluid from the Mare with Juvenile Galactorrhea

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Abstract: Extracellular particles (EPs) were investigated by interferometric light microscopy (ILM) in the udder fluid from the mare with juvenile galactorrhea. Number density n and hydrodynamic diameter D_h of EPs were measured. The samples were taken from a 1 year old Posavje mare. Higher number density (n) of nano - sized EPs were found in the whole fluid in comparison with the skimmed fluid, the difference was statistically significant which is the opposite from the mare's mature milk or colostrum which was shown in our previous investigation when mature mare milk and colostrum were investigated. While the value of the udder fluid n was considerably lower than in the mature mare milk, the values of D_h in the respective samples were within the error of the method. The value of D_h was higher in the skimmed fluid in comparison with the whole fluid, and the difference was statistically significant.

Keywords: Extracellular vesicles; Light scattering; Vesicle characterization; Mare; Udder fluid; Milk; Nanovesicles

1. Introduction

1.1. Milk as a complete food

Mare's milk is the most important nutritional resource for foals during the first months of life. It contains proteins (corpuscular casein and dissolved whey proteins), lipids (fat globules), carbohydrates (milk sugar - lactose), vitamins and minerals (Ca^{2+} , P^+ , K^+ , Na^+). It has antimicrobial activity and antiviral activity. (Musaev et al., 2021; Malacarne et al., 2002). Human and cow milk contains extracellular particles like corpuscular casein micelles, fat globules and extracellular vesicles. (Hu et al., 2021). Here, we investigated the extracellular particles from the fluid of the mare with juvenile galactorrhea. The concentration was measured by interferometric light microscopy.

1.2. What is juvenile galactorrhea in the mare?

Juvenile galactorrhea in the mare refers to milk secretion in a young female horse (mare or filly) that has not been bred or is not pregnant. It is an inappropriate lactation in a non-pregnant, immature mare, usually due to hormonal dysregulation. In a normal situation, milk production in mares is triggered late in pregnancy under the influence of hormones like prolactin and estrogen. In juvenile galactorrhea, this process happens abnormally early, typically in immature or prepubertal fillies. It occurs without pregnancy or foaling (McCue & Sitters, 2011; Chavatte, 1997). Mares or fillies have enlarged udder (mammary gland) with milk or milk-like discharge – "fluid" from the teats.



Figure 1. The udder of a maiden mare is shown on the left image (Image from: <https://wellcomecollection.org/works/a2j9qt79/images?id=brwex7sh>). On the right image the udder of a maiden mare with juvenile galactorrhea is shown. An enlarged teat is clearly visible.

2. Material and Methods

2.1. Milk Sampling

For interferometric light microscopy either udder fluid was milked by hand from an 1 year old Posavje (breed) mare. The fluid was collected into tubes VACUETTE® TUBE 3 ml Z No Additive 13x75 white cap-black ring, non-ridged (Greiner AG, Kremsmünster, Austria). To obtain skimmed fluid, whole fluid was centrifuged at 300 g for 15 min. This procedure was repeated twice. The "cream" was removed from the top using a pipette with the tip shortened for 2 mm by scissors. The tubes with colostrum and milk are shown in **Figure 2**.



Figure 2. The left tube contains udder fluid of the mare with juvenile galactorrhea and the right tube the normal mare milk.

2.2. Interferometric Light Microscopy (ILM)

The average hydrodynamic diameter (D_h) and the number density of small particles in milk were determined by interferometric light microscopy using Videodrop (Myriade, Paris, France) as described previously (Romolo et al., 2022). Before measurement the milk was diluted 100 $\times$ by saline for injections (Braun, Melsungen, Germany) to obtain a measurable dilution. Signals of the saline were under the detection limit. The threshold value 4.2 was used. 7 μ L of sample was placed between cover glasses and illuminated by 2W blue LED light. The light scattered on the particle was imaged by a bright-field microscope objective and allowed to interfere with the incoming light. The image was recorded by a complementary metal–oxide–semiconductor high resolution speed camera. The obtained pattern that includes contrasting black and white spots was recognized as a particle and its position in the sample was assessed. Number density of the particles is the number of the detected particles within the detected volume (e.g. 15 pL). D_h was determined by tracking the position of the imaged particle within the recorded movie. It was assumed that particles undergo Brownian motion due to collisions with surrounding particles. The diffusion coefficient D of the motion of the particle is taken to be proportional to the mean square displacement d of the particle between two consecutive frames taken in the time interval Δt , $\langle d^2(\Delta t) \rangle = \langle 4D \Delta t \rangle$, where t is time, and D is diffusion coefficient. D_h was estimated by assuming that the particles were spherical and using the Stokes-Einstein relation $D_h = k_B T / 3\pi\eta D$, where k_B is the Boltzmann coefficient, T is temperature and η is viscosity coefficient. Each particle that was included in the analysis was tracked and processed individually and the respective incident light signal was subtracted from each image. Processing of the images and of the movies was performed by using the associated software QVIR 2.6.0 (Myriade, Paris, France) (Romolo et al., 2022).

2.3. Light microscopy

Samples were placed into observation chamber, created between two cover glasses delimited by silicon grease and observed by the Nikon Eclipse 2000-S inverted optical microscope.

2.4. Statistical analysis

All measurements were performed in triplicates and presented by the average values and standard deviations. The differences were evaluated by the t-test using the Excel software. The value $p = 0.05$ was taken as a threshold for statistical significance.

3. Results

Higher number density (n) of nano - sized EPs were found in the whole fluid in comparison with the skimmed fluid, the difference was statistically significant (**Figure 3**). The average hydrodynamic diameter D_h was larger in the skimmed fluid in comparison with the whole fluid, the difference was statistically significant (**Figure 3**). The difference between the average hydrodynamic diameters D_h was within the error of the method.

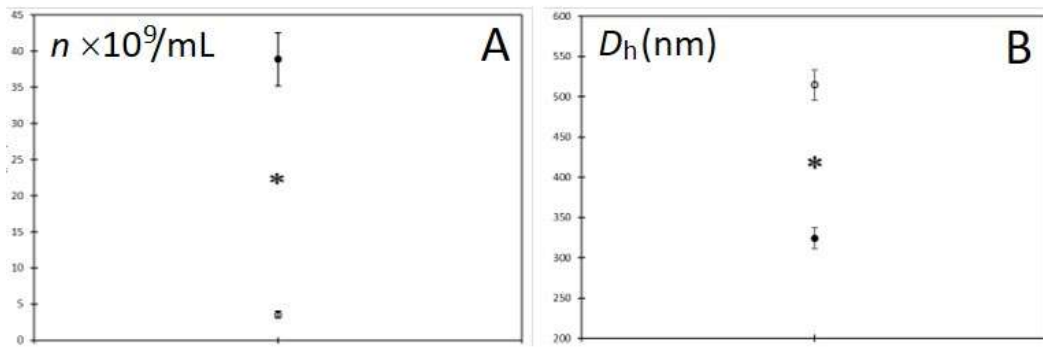


Figure 3. Average number density n (left) and average hydrodynamic diameter D_h of EPs in the mare whole (full circles) and skimmed (empty circles) udder fluid. The error bars represent standard deviations. Asterisk (*) represents statistically significant difference between the whole and the skimmed milk results.



Figure 4. Optical microscope images of : whole fluid (left image), skimmed fluid (middle image) and fluid supernatant – “cream” (right image). Magnification 600x.

4. Discussion

The number density of EPs n was higher in the whole fluid in comparison with the skimmed fluid, the difference was statistically significant (**Figure 3**). In a previous study of mare's colostrum and milk, the number density of EPs was higher in the colostrum than in milk (Arko et al., 2024b). The value of n in the “udder fluid” was much lower than in the mature mare milk from our previous investigation.

D_h was larger in the skimmed fluid in comparison with the whole fluid, the difference was statistically significant (**Figure 3**). A similar feature was observed in the mare's mature milk at day 7 after parturition (Arko et al., 2024b). The number density of micro and nano-sized particles n in skimmed mature equine milk measured by interferometric light microscopy and flow cytometry was observed when compared to the whole mature equine milk, and the differences were statistically significant (Arko et al. 2024a). Higher number density of EPs was found in the skimmed equine colostrum and milk when compared with the whole milk, but the difference was statistically significant only on day 7 after the parturition (Arko et al., 2024b).

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Research

Understanding Nature in Early Adolescence: Conceptions among Urban Middle School Students

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Abstract:

This qualitative study investigates how Austrian sixth-grade students attending urban academic secondary schools understand the concept of nature. Within the context of Education for Sustainable Development, the study focuses on students' human-nature relationships, because conceptions of nature may shape emotional engagement, environmental attitudes, and later pro-environmental behaviour. Data were collected through an anonymous questionnaire administered to 324 students from 14 classes in four schools located in urban areas. The analysis focused on the open-ended question "What is nature to you?" Valid responses (n = 306) were analysed using qualitative content analysis. An inductively developed coding scheme identified eleven main categories describing students' conceptions of nature. The most frequent categories were ecosystems (44.4%), living nature (41.2%), and leisure and recreation (34.0%). Students most often referred to forests, plants, animals, green spaces, and opportunities for relaxation, physical activity, and spending free time outdoors. Abiotic elements, aesthetic descriptions, and emotional associations such as joy, freedom, calmness, and affection were also present, but less frequent. By contrast, environmental protection, untouched nature, and rural references were rarely mentioned. The findings suggest that students mainly understand nature as a familiar, living, aesthetically pleasing, and emotionally meaningful space, rather than primarily as a system requiring protection or as a sphere independent of human influence. These results highlight the need for biology and sustainability education to build on students' everyday experiences while strengthening conceptual links between nature, ecological interdependence, human impact, and environmental responsibility in urban learning contexts for future sustainable action and reflection.

Keywords: Education for Sustainable Development; Human-Nature Relationship; Middle School Students; Urban Environment

1. Introduction

1.1. Education for Sustainable Development

Human survival depends on nature; nevertheless, natural resources are often used as if they were inexhaustible. To illustrate the increasing impact of human activities on the Earth system, Crutzen & Stoermer (2000) proposed the term Anthropocene to describe a new geological epoch shaped by human influence. Climate change, the increasing frequency of extreme weather events, and the ongoing loss of biodiversity can be understood as consequences of human action (Cook et al., 2016; Folke et al., 2021). Reducing these negative impacts requires profound changes in human lifestyles and a transition towards more sustainable ways of interacting with the planet (Oskamp, 2000; Crutzen, 2002). In this context, the concept of sustainability has become highly significant.

One widely used definition of sustainability was introduced in the Brundtland Report, *Our Common Future*, published in 1987. Sustainable development is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Hauff, 1987). The continuing relevance of sustainable development is also reflected in the United Nations’ Agenda 2030 and its 17 Sustainable Development Goals (SDGs), through which all member states committed themselves to promoting a more sustainable relationship with the Earth (UN, 2015). Since the SDGs comprise ecological, economic, and social dimensions, Education for Sustainable Development (ESD) is considered a key approach to their implementation (UN, 2017). ESD is inherently interdisciplinary and aims to enable learners to act in environmentally responsible ways while also considering the economic and social dimensions of sustainability (UNESCO, 2014).

Promoting environmentally responsible behavior, however, requires more than the transmission of environmental knowledge. Several studies have shown that knowledge alone is not sufficient to foster pro-environmental action (Nisbet et al., 2009; Otto & Pensini, 2017). Instead, the human–nature relationship plays an essential role. This relationship is reflected, among other aspects, in an individual’s connectedness to nature. A high level of nature connectedness has been associated with more environmentally responsible attitudes and behaviors (Clayton, 2003; Clayton et al., 2021; Davis et al., 2009; Dutcher et al., 2007; Nisbet et al., 2009). In addition to nature connectedness, students’ individual understanding of nature provides insight into how they relate to nature and may shape their behavior towards it (Dittmer & Gebhard, 2020; Meske, 2011).

Environmental education is particularly relevant for younger students, as educational interventions at this age may have stronger and more lasting effects on nature connectedness and later environmental behavior than interventions targeting older learners (Liefländer et al., 2013; Wells & Lekies, 2006). Understanding students’ human–nature relationships can therefore provide important implications for school practice. It enables educators to connect teaching with students’ existing conceptions of nature and to design learning environments that support both ecological understanding and emotional engagement with nature.

Therefore, the aim of the present study is to investigate the human–nature relationship of Austrian sixth-grade students attending academic secondary schools in urban areas. Particular attention is given to students’ individual understanding of nature, explored through the open-ended question: “What is nature to you?”

1.2. Human-nature relationship

One influential approach to conceptualizing the human–nature relationship is Wilson’s biophilia hypothesis. Wilson (1984) defines biophilia as the “innate tendency to focus on life and lifelike processes” (p. 1). According to this perspective, humans possess an inherent inclination towards living organisms and natural processes. Wilson (1993) later specified this tendency as an emotional affiliation with other forms of life. Biophilia is therefore understood not merely as an interest in nature, but as a deep-rooted emotional connection that may have developed through human evolution. Kellert (1993) similarly argues that human attachment to nature may have offered evolutionary advantages and contributed to survival.

Kellert (1993) expanded the concept by identifying nine values of biophilia: utilitarian, naturalistic, ecologicistic-scientific, aesthetic, symbolic, humanistic, moralistic, dominionistic,

and negativistic. These values describe different ways in which humans relate to nature. For example, the utilitarian value refers to the practical and material use of nature, while the naturalistic value describes the satisfaction derived from direct contact with natural environments. The aesthetic value concerns the attraction to natural beauty, whereas the humanistic value concerns emotional attachment and affection for nature. The moralistic value includes ethical responsibility and spiritual respect for nature. Importantly, Kellert also included negative or ambivalent dimensions, such as fear, aversion, domination, and control, showing that human–nature relationships may range from attraction to rejection. Several studies have indirectly supported the relevance of the biophilia hypothesis. Kahn (1999), for example, provides an overview of empirical findings indicating children’s affinity for nature. Lumber et al. (2017) further show that engagement with nature through naturalistic, aesthetic, symbolic, humanistic, and moralistic pathways can strengthen nature connectedness. However, the biophilia hypothesis has also been criticized. Joye & De Block (2011) question its evolutionary explanation, while Kahn et al. (2009) argue that the concept is so broad that it is difficult to falsify empirically.

For this reason, the present study does not treat biophilia as a hypothesis to be tested. Instead, following Kahn et al. (2009), biophilia is used as a theoretical construct for interpreting students’ human–nature relationships and their individual understandings of nature. The main research question of the study was how secondary school students understand the concept of nature.

2. Materials and Methods

In this study, we follow a qualitative approach. Qualitative inductive research methods were adopted (Mayring, 2015). An anonymous questionnaire was used to collect the data.

2.1. Sample and Methods

The study was part of a broader longitudinal project investigating environmental attitudes among Austrian middle school students. For this paper, we focused solely on the open question of understanding nature and sociodemographic data. The students’ understanding was assessed using the open-ended question, “What is nature to you?”

The study sample consisted of 324 Austrian students in 6th grade (second year of lower secondary education) attending academic secondary schools. In total, 14 classes participated in the study. Data were collected at four schools located in urban regions. Three of these schools were in Vienna (1st, 2nd, and 18th districts), and one was in Lower Austria. Of the 324 participating students, 147 were female (45.5%), and 176 were male (54.5%). One student provided an unclear response to the gender question. The students’ ages ranged from 10 to 14 years, with a mean age of 11.28 years ($SD = 0.56$).

2.2. Data analysis

The analysis was conducted with the Qualitative Data Analysis (QDA) software MAXQDA 2022, which also allowed a semi-quantitative analysis (e.g. the occurrence of technical terms) (Rädiker & Kuckartz 2019). The coding was dominantly inductive, focusing on the most common patterns emerging from the dataset. The coding frame was data-driven, with codes and themes emerging from the students’ descriptions. The author and one trained graduate research assistant applied the coding guideline, which was continuously adapted throughout the analysis through iterative reviews, discussions, categorization, and re-coding. The final coding structure was also validated through discussions and refinement. We first did the analysis in German and then translated a selection of the students’ statements for our manuscript. The translation was done by a bilingual researcher and then retranslated to confirm the original meaning and information. Additionally, all translated descriptions were discussed with the bilingual team (native languages: German and English), as we are aware of the risk that information may be changed or misrepresented.

The developed coding guideline includes a clear category definition and an example from the student’s answers for each category to ensure the validity of the coding scheme (Table 1).

Table 1: Coding scheme for students' understanding of nature

Rank	Main Category	Definition	Anchor example
1	Ecosystems	Students describe nature by referring to ecosystems such as forests, meadows, and lakes. Urban green spaces, such as parks and gardens, are also included in this category as urban ecosystems.	"For me, nature means forest and meadow." (male, 11 years)
2	Living nature	Students describe nature through living organisms, such as plants, animals, fungi, or more generally, as something living.	"Calmness, love, forests, life, air." (female, 11 years)
3	Leisure and recreation	Students describe nature as a place for leisure activities. This includes playing, physical activity in nature, nature as a meeting place or place of discovery, and nature as a recreational space.	"A recreational space where I like to spend my free time. You can observe and discover many things, and it is good for me." (female, 12 years)
4	Abiotic nature	Students describe nature by referring to its non-living components, such as water, rocks, oxygen, and air.	"Nature is freedom. Nature is fresh air. Minecraft." (male, 12 years)
5	Aesthetic description	Students describe nature as something beautiful or associate it with the colour green.	"I think nature is the green with different animals and the fresh air. Unfortunately, we are currently destroying it." (male, 12 years)
6	Emotions and attitudes	Students describe their affection or aversion towards nature and the feelings that nature evokes in them. Statements expressing enjoyment, enthusiasm, or excitement about nature are also included in this category.	"Nature is the best thing in the world for me; I cannot live without nature. I forget all stressful things when I am in nature." (female, 12 years)
7	Freedom	Students describe nature as freedom or as a place that evokes a feeling of freedom.	"A place where I can feel free." / "For me, nature is freedom. There you can do anything you want." (female, 11 years)
8	Importance of nature	Students describe nature using the general term "important" or as a basis for human life.	"Nature is very important to me because without nature, there is no oxygen." (male, 11 years)
9	Almost free from humans	Students describe nature as neither created nor influenced by humans, or as a place where almost no humans are present.	"For me, nature is everything that has not been created by humans." (male, 12 years)
10	Environmental protection	Students describe nature as something worth protecting or state how nature or the environment can be protected.	"You should not throw rubbish on the street or into the sea." (female, 11 years)
11	Rural reference	Students describe nature through buildings commonly found in rural areas or through rural places where acquaintances or relatives live.	"Forest and meadow. At both of my grandparents' villages." (male, 11 years)

3. Results

The eleven inductively developed main categories, including definitions and anchor examples in the original wording, are presented in **Table 1**.

As shown in **Figure 1**, “ecosystems” (44.4%) was the most frequently mentioned category, followed by “living nature” (41.2%) and “leisure and recreation” (34.0%). Approximately one fifth of the students referred to “abiotic nature” (20.9%) and provided an “aesthetic description” of nature (18.0%). “Emotions/attitudes” were mentioned by 14.7% of the respondents. These six categories are further divided into subcategories, which are discussed in more detail. Among the categories without subcategories, “freedom” (9.2%) was the most frequently mentioned, followed by “importance of nature” (6.5%). The remaining three categories were each mentioned by fewer than 5% of the surveyed students.

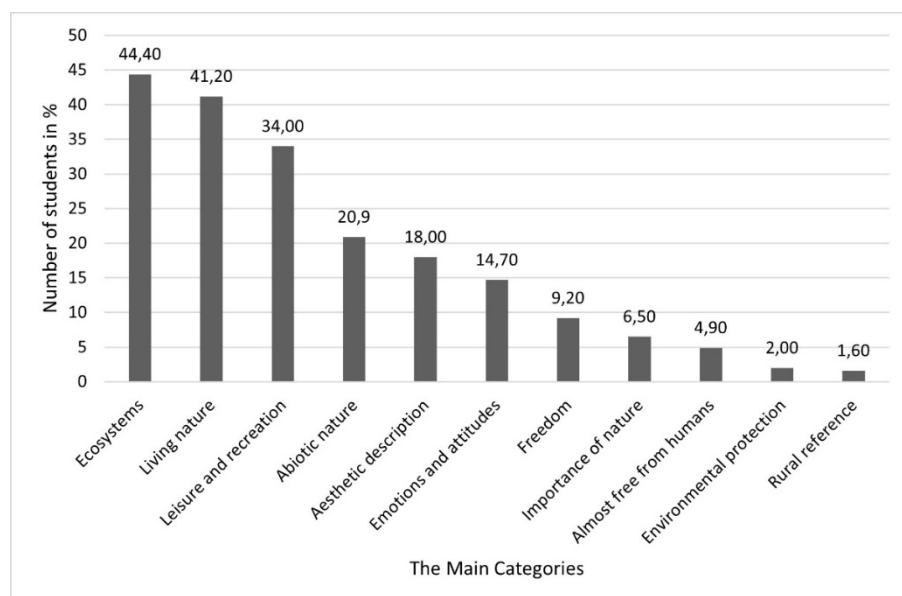


Figure 1. Percentage frequencies of the main categories regarding 6th-grade students' understanding of nature. The percentages refer to the valid responses ($n = 306$) and indicate what percentage of students mentioned the respective category. In total, the percentage exceeds 100%, as each student could mention several categories.

3.1. Ecosystems

The category “ecosystems” consists of the five subcategories “forest,” “meadow,” “green spaces,” “aquatic ecosystems,” and “other ecosystems.” In total, 136 students described nature as an ecosystem or explicitly mentioned ecosystems. Approximately 83% of all students mentioned an ecosystem referring to forests, around one-third to meadows (33.1%), and one-fifth to green spaces, such as parks and gardens (20.6%). Aquatic ecosystems were mentioned by 20 of the 136 students (14.7%). Other ecosystems, such as deserts and caves, were mentioned by only a small proportion of the students (3.7%).

Some examples:

- “Forest, animals of all kinds, natural rivers, sea, plants” (female, 11 years old)
- “Rivers, mountains, desert, caves, forest, sea” (male, 11 years old)

3.2. Living Nature

The category “living nature” includes the subcategories “flora,” “fauna,” “fungi,” and “living organisms”. Overall, the category “living nature” was mentioned by 126 students. “Flora” was described most frequently (72.2%), followed by “fauna” (61.1%). Eight of the 126 students used the term “living organisms” (6.4%), and four mentioned “fungi” (3.2%) as an example of nature.

For example:

- “Nature means to me, for example, many plants, animals, green spaces and yes. Many living beings” (female, 14 years old)
- “Plants, fungi, forests, lakes, mountains, seas, streams and rivers” (male, 11 years old)

3.3. Leisure and Recreation

The category "leisure and recreation," which was described by 104 students, is divided into five subcategories. More than half of all students who mentioned "leisure and recreation" described nature as a "place of recreation" (53.8%). The second most frequently mentioned subcategory was "physical activity in nature" (40.4%). Nature was described considerably less frequently as a "place of discovery" (10.6%), a "meeting place" (7.7%), or a "place to play" (6.8%).

For example:

- "In the forest or somewhere where you can spend time without traffic noise." (female, 11 years old)
- "To me, nature is pure relaxation!" (female, 11 years old)
- "Lots of trees, relaxing, climbing, hiking, having peace and quiet" (female, 12 years old)

3.4. Abiotic Nature

The category "abiotic nature" is divided into the three subcategories "Air," "Mountains," and "Other Parts of abiotic nature" and was mentioned by 64 students. Most students who mentioned parts of abiotic nature referred to "Air" (64.1%). The subcategory "Mountains" was mentioned second most frequently (35.9%). The remaining responses fall under other parts of abiotic nature or abiotic factors, such as sun, water, snow, wind, and stones (17.2%).

For example:

- "I think of lots of fresh air (...)" (female, 11 years old)
- "Forest, wind, sun, mountains, animals, huts, long meadows" (male, 11 years old)

3.5. Aesthetic

The category "aesthetic description" consists of the subcategories "green color" and "beauty." It was mentioned by 55 students, with 34 responses assigned to the subcategory "green color" (58.2%) and 24 responses to the subcategory "beauty" (43.6%).

For instance:

- "Home of animals and the greenery of the world" (male, 11 years old)
- "To me, nature is something especially beautiful. I feel most comfortable there." (male, 11 years old)

3.6. Emotions and attitudes

The category "emotions" is divided into "positive emotions" and "negative emotions". It was mentioned by 45 students, almost all of whom described a positive emotional connection to nature (95.6%). Two students expressed negative emotions toward nature (4.4%).

Their responses are presented below:

- "Something special. Nature is like a good friend to me (...)" (female, 11 years old)
- "Nature makes me happy. I like nature." (female, 11 years old)
- "Nature is beautiful, but I hate mosquitoes and I hate insects" (male, 11 years old)
- "Very beautiful, can be boring, can smell musty" (female, 11 years old)

4. Discussion

The findings indicate that Austrian middle school students' understanding of nature is multidimensional but strongly shaped by concrete, familiar natural elements. Most frequently, students described nature through ecosystems, especially forests, as well as through living nature, leisure and recreation, and, to a lesser extent, abiotic components, aesthetic qualities, and emotional responses. This pattern is broadly consistent with previous research showing that children and adolescents often conceptualize nature primarily through visible natural elements such as plants, animals, landscapes, forests, water, and other ecosystems (Aaron & Witt, 2011; Bolzan-de-Campos et al., 2018; Collado et al., 2016; Hahn, 2018; Kleespies et al., 2021; Pointon, 2014; Tillmann et al., 2019).

A particularly prominent result is the central role of forests in students' conceptions of nature. Among those who mentioned ecosystems, the forest was by far the most frequent example. Similar findings have been reported by Hahn (2018) and Kleespies et al. (2021), who also identified forests as highly salient elements in children's and adolescents' understanding of nature. This dominance may be explained by several interacting factors. First,

forests are highly visible in Austria, where forested areas constitute a substantial part of the landscape. Gebhard (2020) further highlights the psychological and cultural significance of forests, which may represent freedom, calmness, mystery, and emotional depth. Third, the school curriculum and biology textbooks may reinforce this emphasis, as forests are prominently featured in the Austrian biology curriculum for this age group. However, because the timing of classroom instruction was not controlled, it remains unclear whether recent forest instruction influenced students' responses.

Students also frequently described nature through living organisms, especially plants and trees. This finding is noteworthy in relation to the concept of "plant blindness" proposed by Wandersee & Schussler (1999), which holds that plants are often overlooked relative to animals. In the present findings, however, plants were more frequent than animals, although this may partly be due to the inclusion of trees in the plant category. The strong presence of trees may again reflect their association with forests and their symbolic importance in children's perceptions of nature (Gebhard, 2020).

Beyond ecological elements, many students understood nature as a place for recreation, relaxation, movement, and leisure. This supports earlier findings that children's definitions of nature often include outdoor activities and personal experiences (Aaron & Witt, 2011; Collado et al., 2016; Tillmann et al., 2019). The frequent description of nature as a place of calmness and recovery also corresponds with research demonstrating positive effects of nature contact on mental and physical health, including stress reduction, attention restoration, and psychological well-being (Claßen & Bunz, 2018). In terms of Kellert's (1993) biophilia framework, these responses reflect a naturalistic value orientation, in which nature is appreciated for its positive effects on human experience.

Aesthetic and emotional dimensions were also present, although less dominant. Students associate nature with the color green, beauty, freedom, joy, relaxation, and affection. These findings indicate that nature understanding is not merely cognitive or ecological, but also relational and effective. This supports Meske's (2011) argument that concepts of nature provide insight into children's relationship with nature. At the same time, explicitly negative emotions were rare, suggesting that nature was predominantly associated with positive experiences. Unlike findings from contexts where nature may be linked to danger or insecurity (Adams & Savahl, 2015), Austrian students rarely described nature as threatening.

Interestingly, nature conservation and untouched nature were mentioned only rarely. This contrasts with studies in which environmental protection or human-free nature played a stronger role (Collado et al., 2016; Hahn, 2018; Vining et al., 2008). One possible explanation is the participants' urban background, as previous studies suggest that rural children more often refer to conservation, food production, and human dependence on natural resources (Bolzan-de-Campos et al., 2018; Collado et al., 2016). Overall, the results show that students' understanding of nature is shaped by ecological knowledge, everyday experience, cultural symbols, school learning, and emotional relationships. Future studies should complement open written responses with interviews to clarify whether the absence of references to humans, conservation, or untouched nature reflects genuine conceptual exclusion or simply the limits of the chosen method.

5. Conclusions

The findings show that Austrian students' understanding of nature largely corresponds with previous research. Differences mainly concern the frequency of individual categories and the way categories are defined, which is to be expected in qualitative research. More than 40% of the students described nature through ecosystems, particularly forests, or through living nature, with plants, especially trees, being mentioned slightly more often than animals. In addition, one quarter of the students referred to abiotic elements of nature, while around one-fifth associated nature with green and/or beauty.

Furthermore, one-third of the students integrated aspects of leisure and recreation into their understanding of nature. Their responses also reveal an emotional relationship with nature: students described nature through feelings such as freedom, relaxation, and joy,

while some expressed affection using words such as “love”, “great”, and “wonderful”. However, nature conservation was rarely included in students’ descriptions. Similarly, the idea of untouched nature was mentioned only infrequently, unlike in several previous studies. Overall, the results suggest that students mainly understand nature as a familiar, living, aesthetically pleasing, and emotionally meaningful space, but less often as a system requiring protection or as a space independent of human influence.

Acknowledgment: I would like to thank all the students who took part in the study and completed the questionnaire.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki. For this study, ethical approval was not required. The sample was informed in advance that participation is voluntary, and that data collection takes place anonymously. According to Austrian law, approval of an ethics committee was not necessary as this study did not involve patients, was non-invasive, and participation was voluntary and anonymous.

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Research

Interpretation of Atomic Theory and Invisible Particles in *De Rerum Natura*: A STEAM Approach through Music, Poetry, and Digital Heritage

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Abstract:

This paper explores the interpretation of Epicurean atomistic theory and the visualization of invisible particles and structures inspired by Lucretius' *De Rerum Natura* through a STEAM (Science, Technology, Engineering, Arts, and Mathematics) framework. This study is guided by the research question: *How do simple elements combine to generate complex structure?*

The discussion is based on the author's original methodologies, SMS (Stories based on Music about Science) and SMH (Stories based on Music about Heritage), which integrate scientific concepts, artistic expression, music, and cultural heritage. Drawing on Book I of *De Rerum Natura*, in which Titus Lucretius Carus presents one of the earliest systematic accounts of Epicurean atomism, the paper reinterprets the concepts of *semina rerum* ("seeds of things"), *corpora prima* ("first bodies"), and *primordia rerum* ("first beginnings") through three interconnected components: poetry, music, and digital visualization.

The poetic component consists of an original adaptation based on William Ellery Leonard's English translation of Book I, complemented by passages from the original Latin text. The musical component is represented by the author's original composition under the artistic name of Aleona von Sultanova, *Carmen Philosophicum*. The visual component employs digital interpretations inspired by *Splendor Solis*, a sixteenth-century illuminated manuscript attributed to Salomon Trismosin, which functions here as a symbolic and cultural framework for representing hidden processes, transformation, and the emergence of visible forms from invisible constituents. By bringing together classical philosophy, music, poetry, digital heritage, and contemporary perspectives from biophysics, the study proposes an interdisciplinary model for STEAM education and public engagement. This project was presented at the European Joint Theory/Experiment Meeting on Membranes (28 January 2026, in Ljubljana), where *Carmen Philosophicum* was also introduced alongside the related STEAM project *Architecture of the Invisible: Membranes*.

Keywords: Biophysics; *De Rerum Natura*; STEAM; SMS (Stories based on Music about Science); SMH (Stories based on Music about Heritage); Tiny particles.

1. Introduction

1.1. *De Rerum Natura* (Book I): From Epicurean Physics to Contemporary Biophysics

De Rerum Natura (On the Nature of Things) is a six-book philosophical poem written by the Roman poet Lucretius (c. 99–55 BCE) to introduce Greek Epicurean philosophy to a Roman audience. Drawing on the teachings of the Greek philosopher Epicurus (341–270 BCE), Lucretius explains the nature of the universe through natural causes, arguing that all things are composed of invisible primary constituents moving in the void.

Albert Einstein, in his foreword to Hermann Diels' 1924 translation of *De Rerum Natura*, admired Lucretius for his conviction that nature could be understood through reason and causal relationships. Einstein regarded *De Rerum Natura* as a lasting example of a scientific worldview grounded in observation, rational inquiry, and the search for natural explanations of the physical world (O'Rourke, 2020). A century later, modern studies of complex systems, exemplified by the work of Giorgio Parisi (the 2021 Nobel Prize in Physics), continue to investigate how large-scale structures and behaviours emerge from the interactions of simple constituent elements.

Although Lucretius' "atomistic" theory differs fundamentally from modern scientific knowledge, his central question remains relevant to contemporary biophysics: - how do invisible constituents give rise to observable structures and processes?

Bailey (1940) writes that in Book I Lucretius argues for the existence of infinitely many "atoms" moving within infinite space and maintains that the formation of the world resulted not from divine planning but from the natural interactions of these elementary particles. He emphasizes that Lucretius possesses a remarkable ability to convert philosophical argument into visual imagery, allowing abstract concepts to be perceived almost as concrete pictures.

In *De Rerum Natura*, Lucretius explains the visible world through the interactions of unseen constituents (examples: *semina rerum* and *corpora prima*) moving within the void (inane). His attempt to explain visible phenomena through invisible entities resonates with modern efforts to visualize tiny particles and microscopic structures in biological samples. Modern biophysics similarly investigates how atoms, molecules, membranes, and extracellular vesicles organize into increasingly complex biological systems. While separated by more than two millennia and based on different scientific frameworks, both approaches seek to understand how complex forms emerge from simpler underlying constituents.

1.2. *Carmen Philosophicum*: Book I

Drawing on Book I of *De Rerum Natura*, the author presents *Carmen Philosophicum* as an original musical interpretation of Lucretius' philosophy. The composition is based on a poetic adaptation of William Ellery Leonard's English translation of the summary of Book I and incorporates selected passages from Lucretius' original Latin text, intentionally inserted in the poem in English language. Drawing on Book I of *De Rerum Natura*, the author presents *Carmen Philosophicum* as an original musical interpretation of Lucretius' philosophy. The composition is based on a poetic adaptation of William Ellery Leonard's English translation of the summary of Book I and incorporates selected passages from Lucretius' original Latin text, intentionally inserted into the English-language poem. The work is presented under the artistic name Aleona von Sultanova and is available on YouTube as Book I. *De Rerum Natura* by Lucretius): https://www.youtube.com/watch?v=47jhNO0_8IE *Carmen Philosophicum* was developed within a STEAM (Science, Technology, Engineering, Arts, and Mathematics) framework and integrates three interconnected components: Mu-sic-Poetry-Digital Visualisation (described in Methods).

Together, all these components explore the research question of how simple elements combine to generate complex meaning and structure. Although the philosophical foundations of Lucretius and the symbolic tradition of *Splendor Solis* differ, both provide frameworks for understanding how visible forms emerge from underlying invisible principles.

Although Epicurus and Lucretius are often described as materialists (see, for example, Masi and Verde, 2024; Galloway, 1986), they did not deny the existence of the gods. Rather, they rejected the notion that the gods intervene in the affairs of the world, maintaining instead that divine beings exist in a state of perfect tranquility, detached from human concerns and natural processes. Lucretius' *De Rerum Natura* opens with a celebrated *Hymn to Venus*, in which Venus is invoked not merely as the Roman goddess of love but as the generative force of Nature itself. This poem attracted the attention of John Evelyn, an early

Fellow and founding member of the Royal Society, who in 1656 published *An Essay on the First Book of T. Lucretius Carus De Rerum Natura* (Evelyn). According to Butterfield (2015), Evelyn's translation formed part of the early modern rediscovery of Lucretius. Significantly, the First Book contains both the famous invocation to Venus and the poem's foundational philosophical arguments concerning nature, matter, and the structure of the universe.

Inspired by Lucretius' *Hymn to Venus*, this composition was first written and performed in October 2024 as a musical introduction to Book I of *De Rerum Natura* during the Socratic Lectures Symposium. It later became part of the broader philosophical-musical project *Carmen Philosophicum*, which was presented at the *European Joint Theory/Experiment Meeting on Membranes* on 28 January 2026 alongside another STEAM-related composition, *Architecture of the Invisible: Membranes*.

1.3 Symbols in Words and Images: Lucretius' Invisible Particles and the Imagery of Splendor Solis
Epicurus adopted the Greek concept of atomos ("indivisible" or "uncuttable" particle; from a- = "not" and tomos = "cut"). Lucretius, however, does not use the Greek term *atomos* and prefers a variety of philosophical Latin expressions to describe the fundamental constituents of reality: *semina rerum* ("seeds of things"), *corpora prima* ("first bodies"), and *primordia rerum* ("first beginnings"). He also occasionally uses broader or more poetic expressions such as *materies* ("matter") and *genitalia corpora* ("generative bodies"). Through this diverse vocabulary, Lucretius emphasizes not only the material nature of these invisible constituents but also their generative role in producing the observable world.

"*Splendor Solis*" is employed by the author of this paper as a visual interpretation of Lucretius' "*semina rerum*". The symbolism of *Splendor Solis* lends itself naturally to this reading. The manuscript repeatedly depicts: hidden processes, transformation of matter, emergence of new forms, cycles of dissolution and recombination, relationships between microcosm and macrocosm. "*Splendor Solis*" seems to be identical with that of the 22 keys of the Tarot, and they observe the same order, and it "has both a Physical-Alchemical, and a Spiritual-Mystic meaning" (Trismosin, & Godwin, 2021, pages 8-9).

Among the images of *Splendor Solis*, the peacock may be interpreted as a visual analogue of Lucretius' *semina rerum* (Figure 1, Table 1). In alchemical symbolism, the peacock represents transformation and the emergence of complexity from hidden processes.

The multitude of colours generated from a single living form reflects the transition from simple elements to complex structures. The presence of musical instruments further reinforces the idea of harmony and organisation, suggesting that invisible principles may generate both visual and musical order. In this respect, the image also provides a symbolic response to our research question:

"How do simple elements combine to generate complex meaning and structure?"

According to Dovgii et al. (2015) in the Christian tradition the peacock was associated with immortality, in alchemy it symbolized the attainment of the Prima Materia (First Matter) and the successful completion of the first stage of the Great Work (Magnum Opus or Great Work).

This can create a bridge to Lucretius: *semina rerum* - as the invisible origins of visible forms and Prima Materia as the original substance from which transformation proceeds. Thus, Peacock (Cauda Pavonis) symbolizes as the emergence of multiplicity, colours, and complexity from an underlying process.

In the Image of the Peacock there are depicted musical instruments connecting all three components: Poetry - meaning, Music - harmony, Image - visual structure. Trismosin & Godwin (2021, p.18) notes that "Art produce extraordinary things", and "out of the aforesaid natural beginnings such as Nature of herself would never be able to create". "For unaided Nature does not produce things whereby imperfect metals can in a moment be made perfect, but by the secrets of our Art this can be done. Here Nature serves Art with Matter, and Art serves Nature with suitable Instruments and method convenient or Nature to produce such new forms".



Figure 1. According to Trismosin & Godwin, 2021 p. 57), inside the Cucurbit there is the painted peacock who is looking down upon a group of musicians: “one of them is playing a guitar, and another a viol; a lady dressed in red and gold also is playing a viol, while another lady in blue and gold and one in yellow and gold are singing a concert”. Among the images of *Splendor Solis*, the peacock may be interpreted as a visual analogue of Lucretius' *semina rerum*. The presence of musical instruments further reinforces the idea of harmony and organisation, suggesting that invisible principles may generate both visual and musical order. In this respect, the image also provides a symbolic response to the research question: How do simple elements combine to generate complex meaning and structure?

Table 1. From Simple Elements to Complex Structures: A Comparative Model across Lucretian Philosophy, Language, Music, Visualization, and Biophysics

Elementary principle	Structured combination	Emergent form
Generative principle	Fundamental constituents	Observable world
Semina rerum (seeds of things)	Corpora prima (primary bodies)	Res (Visible bodies/forms or Realities)
Letters	Words	Poem
Notes	Melody	Music
Pixels	Image	Visualisation
Atoms/Molecules	Microscopic biological structure (cells/membranes/vesicles)	Biological systems

2. Methods

2.1. *Stories based on Music about Heritage SMH and Stories based on Music about Science (SMS) Methods*

The SMH and SMS methods were introduced in 2012 year by Istileulova Yelena.

2.1.1. SMH

"Carmen Philosophicum" is written on the basis of the STEAM approach (Science, Technology, Engineering, Arts and Mathematics), using one of the author's original methods - SMH (Stories based on Music about Heritage — a historical, cultural, and scholarly framework). This method, developed in 2012, comprising three elements:

1. Music – an original composition;
2. Poetry – a concise poetic adaptation and summary of Book I of De Rerum Natura, reflecting Lucretius' concepts of semina rerum ("seeds of things"), corpora prima ("first bodies"), and inane ("void"), the literary and scientific heritage of antiquity;
3. Image or Visualisation of the main idea.

Digital Visualization is interpretation inspired by Splendor Solis, a sixteenth-century illuminated manuscript attributed to Salomon Trismosin, employed as a cultural and symbolic framework for representing hidden processes, transformation, and the emergence of visible forms from invisible constituents. Poem - De Rerum Natura - on the nature of the atom. Book I of Lucretius in translation from Latin - is a literary and scientific heritage.

2.1.2. SMS

In the context of Carmen Philosophicum, the emphasis is placed primarily on concepts derived from modern science and their relationship to Lucretian philosophy. In other SMS projects, the author has also employed the related framework Stories based on Music about Scientists. Like SMH, SMS is built upon three core components: storytelling (poetry), original music, and digital visual imagery.

Describing the method in greater detail, Istileulova (2024, p. 141) outlines the conceptual framework of SMS (and SMH) as follows

In the context of *Carmen Philosophicum*, the emphasis is primarily made on the concepts of modern science. In other SMS projects, the author has also employed the framework Stories based on Music about Scientists. Like SMH, SMS is based on three key elements:

Storytelling (poetry); Original music; Digital visual imagery. In Istileulova (2024, p. 141), the method is described in more details. In fact, the SMS (also SMH) method has the following conceptual framework:

1. Research about the scientist of the Past time
2. Story about a Scientist-Polymath of the Past time (mainly, the 17-th -20-th centuries)
3. Key idea of Scientific Innovation, or inspiring facts from the life of Scientist
4. Lyrics (a): written based on research)/or by Scientist himself or construction of the key shorter version
5. Music (supporting the idea of lyrics)
6. Visual Arts (digital images /pictures, video, etc.) to explain the key ideas to those who do not understand the original languages of lyrics (English, Russian, Slovenian, or Latin).
7. Performance (for example Socratic Lectures Symposiums, and other scientific events)

3. Results

These are quintessential Book I: "Semina rerum. Corpora prima." "Bodies and the void" "But from nothing nothing comes, Nor to nothing things return.". The musical component is represented by the author's composition, Carmen Philosophicum (created under the artistic name Aleona von Sultanova), presented here: https://www.youtube.com/watch?v=47jhNO0_8IE

While Lucretius is commonly associated with ancient atomism, his preferred expression semina rerum ("the seeds of things") suggests a broader conception of invisible generative entities underlying the visible world.

This metaphor provides a productive framework for contemporary STEAM interpretations linking ancient natural philosophy with modern scientific visualization. The text of the adapted poem "Carmen Philosophicum":

Lightnings pass through walls of stone,
Iron whitens in the flame,
Rocks ignite and burst apart,
Gold dissolves, yet stays the same.
Warmth and cold through silver creep,
Bronze turns liquid, fire wins—
All we touch and all we see
Shows no solid form within.
Yet true reason calls us back:
There must be something standing fast —
Bodies firm and everlasting,
Seeds from which all forms are cast.
Semina rerum. Corpora prima.
Semina rerum. Corpora prima.
Twofold is the nature known,
Different utterly in kind:
Body stands, and space receives,
One is mass, the other blind.
Where there is the empty place,
Body cannot dwell inside;
Where the body holds its ground,
There the void itself must hide.
Corporibus atque inani.
Bodies and the void remain.
Corporibus atque inani.
Bodies formed in endless plane.
Only where the void resides
Can a thing be crushed or torn;
Fire and cold and seeping damp
Break what space has let be born.
More the void a body holds,
More it trembles, more it bends—
What is solid without void
Never breaks and never ends.
If the primal seeds were not
Everlasting, firm, and sure,
Long ago all things had fallen
Back to nothing, cold and pure.
But from nothing nothing comes,
Nor to nothing things return—
Thus the seeds of all that is
Hold immortal frame and form.

The poem follows the logical progression of Book I: Observation of physical change (lines 1–12), Inference of invisible permanent constituents (lines 13–20), Doctrine of body and void (lines 21–36), Explanation of change through void (lines 37–48), Necessity of eternal first bodies (lines 49–56), The principle that nothing comes from nothing and nothing returns to nothing (lines 57–64)

3.2. *De Rerum Natura and the Concept of Invisible Particles*

Democritus (5th–4th century BCE) was one of the founders of ancient atomism. He proposed that all matter is composed of indivisible constituents moving through empty space (the void). Epicurus (341–270 BCE) further developed Democritus' atomistic theory and incorporated it into a broader philosophical system aimed at explaining nature through natural causes rather than divine intervention. Although most of his works have been lost, written in Ancient Greek, some fragments survive through later sources, particularly the writings of Diogenes Laertius and the Herculaneum papyri.

Finally, Lucretius (c. 99–55 BCE) transmitted Epicurean philosophy to the Roman world through his Latin didactic poem *De Rerum Natura* ("On the Nature of Things"). While the

philosophical foundations derive from Epicurus, Lucretius reinterpreted them in poetic form, employing expressions such as *semina rerum* ("the seeds of things"), *corpora prima* ("the first bodies"), and *primordia rerum* ("the first beginnings") to describe the invisible particles underlying the visible world.

These expressions more accurately reflect Lucretius' own language and philosophical imagery. From the author's perspective, these concepts offer a broader interpretive framework than the modern notion of the atom, allowing for multiple representations of invisible generative structures and different stages in the formation of visible reality.

The poem *Carmen Philosophicum* (see Results) was conceived as a concise poetic adaptation of Lucretius and is based primarily on Book I. Most of the poem is devoted to the fundamental doctrines. In the present study, the original Lucretian terminology is retained rather than replaced by the modern term "atom".

The author of this paper used the original Lucretian terms rather than the modern translation of "atoms". Lucretius' own expressions fit this interpretation much better than the modern word "atom", because from the position of the author it shows different and rich variations and different stages of the "seeds".

3.3 Visualisation

Splendor Solis is regarded as one of the most famous alchemical manuscripts. According to Völlnagel (2011), its miniatures are among the most beautiful and best-known images in the history of alchemical illustration. At the same time, despite its prominence within the Harley Collection and the broader tradition of alchemical manuscripts, many aspects of the work remain uncertain, and comparatively little critical research has been devoted to its historical and symbolic interpretation (Völlnagel, 2011). While Splendor Solis does not represent atoms or microscopic particles in a scientific sense, it provides a rich symbolic language for visualizing invisible processes of transformation and generation. In this respect, the manuscript serves as a visual analogue to Lucretius' concept of *semina rerum*, offering an artistic framework through which hidden structures may be imagined and interpreted (Figure 1).

4. Discussion

Thus, we return to a fundamental question: how do invisible constituents give rise to observable structures and processes? Historians of philosophy commonly describe Lucretius as an atomist. Yet Lucretius himself frequently employs more poetic expressions such as *semina rerum* ("seeds of things"), *corpora prima* ("first bodies"), and *genitalia corpora* ("generative bodies") to describe the invisible constituents underlying the visible world. Although these concepts are related to ancient atomism, they should not be uncritically equated with the modern scientific concept of the atom.

Indeed, some scholars prefer not to translate *semina rerum* simply as "atoms," since the phrase "seeds of things" more accurately reflects Lucretius' own imagery and philosophical vocabulary. The metaphor of the seed evokes generation, growth, emergence, and hidden potential. For a classicist, *semina rerum* signifies the invisible origins of visible things. From a contemporary scientific perspective, the same idea may resonate with atoms, molecules, cells, membranes, extracellular vesicles, and other microscopic entities that participate in the formation of increasingly complex structures. While ancient atomism differs fundamentally from modern science, Lucretius' notion of unseen constituents provides a useful philosophical starting point for contemplating how visible forms emerge from invisible foundations. Lucretius imagined invisible generative principles (*semina rerum*, *corpora prima*); modern chemistry identifies atoms and molecules as fundamental building blocks of matter, while modern biology demonstrates how molecules organize into membranes, cells, and complex living systems.

The author further proposes that Lucretius' expression *genitalia corpora* may be interpreted as reflecting a multilevel process of generation and differentiation. Although Lucretius employs the term primarily in the sense of "generative bodies" or productive constituents of nature, the symbolic perspective adopted in this study invites a broader interpretation. The transition from primordial unity to differentiated forms may be viewed symbolically through the emergence of complementary principles, often represented in later alchemical traditions by male and female figures. Although such an interpretation is

not explicitly present in *De Rerum Natura*, it provides a conceptual bridge between Lucretius' generative vocabulary and the visual symbolism of *Splendor Solis*, where transformation and creation are frequently depicted through the interaction of masculine and feminine elements.

In *De Rerum Natura*, *semina rerum* refers to the generative principles from which all forms arise, while *corpora prima* denotes the fundamental constituents of matter. Through their combinations, arrangements, and movements, these invisible elements give rise to *res* ("things"), namely the visible forms and structures perceived in nature. In the present study, these Lucretian concepts serve as a conceptual model for understanding how simple elements combine to generate increasingly complex forms, meanings, and systems across language, music, visual representation, and biophysics.

Table 1 illustrates a common principle across the domains examined in this study: simple elements combine to generate increasingly complex forms. In Lucretius' philosophy, *semina rerum* and *corpora prima* give rise to *res*, the observable world. Similar patterns can be seen in language (letters–words–poem), music (notes–melody–music), visualization (pixels–image–visualization), and biophysics (atoms and molecules–cellular structures–biological systems). Although these domains differ in their nature and mechanisms, they share the idea that complex forms emerge from the organization and interaction of simpler constituents.

5. Conclusions

Lucretius proposed that nature operates according to laws, that natural phenomena arise from natural causes, that invisible structures underlie visible reality, that matter consists of fundamental constituents, and that the universe can be understood through reason and inquiry. These principles remain central to science today. The research question—How do simple elements combine to generate complex meaning and structure?—operates on several levels within the project.

In Lucretius' philosophy, invisible primary constituents (*semina rerum*, *corpora prima*) combine to form the visible world. In language, individual letters combine to create words and poetic meaning. In music, individual notes form melodies and harmonic structures. In digital visual media, symbols and images generate complex interpretations. The poem therefore functions not only as an adaptation of Lucretian atomism but also as a demonstration of the same generative principle across science, art, and culture: complex structures emerge through the combination and organization of simpler elements.

The present study focuses primarily on Book I of *De Rerum Natura*. Future research may extend this approach to Book II, exploring how the same research question can be investigated through the SMS and SMH methodologies within a STEAM framework.

Conflicts of Interest: The author declares no conflict of interest.

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Research

Diego de Castro: music unites all people

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Abstract:

Diego de Castro was a statistician, lawyer, diplomat and professor, born in Piran. He was renowned for his deep knowledge of the problematic of the Trieste border, about which he wrote extensive works. A primary school in Italian language "Vincenzo e Diego de Castro" in Piran is named after him. As a diplomat and scholar, he stated in one of his final writings that music is the only art that unites all people.

Keywords: Diego de Castro; Piran; Primary school; Tartini; Music experience.

1. Who was Diego de Castro

1.1. *De Castro's birthplace*

Diego de Castro (1907–2003) was born in Piran as the last descendant of an old Piranese family. His birthplace was the Gabrielli family palace, a mid-19th-century building that today houses the “Sergej Mašera” Maritime Museum. According to the website of the “Sergej Mašera” Maritime Museum, the rotunda is a small circular salon of this palace, because of which the building was once called “La Rotonda”. **(Figure 1)**



Figure 1. “La Rotonda,” part of the palace where Diego de Castro was born; today a memorial room dedicated to Diego de Castro in the “Sergej Mašera” Museum in Piran.

The building next to the museum is the Italian-language primary school named after him and after a member of the de Castro family born a century earlier, Vincenzo. The “Vincenzo e Diego de Castro” Primary School is located in the center of Piran and also has branch schools in Lucija and Sečovelje. **(Figure 2)**



Figure 2. Primary School “Vincenzo e Diego de Castro” in Piran.

1.2. The surname *de Castro*

The origin of the surname *de Castro* is particularly interesting. As stated in a publication of the “Vincenzo e Diego de Castro” Primary School (Romanello et al., 1998), it is one of the oldest surnames in Piran (**Figure 3**). The surname *de Castro* derives from the Latin word *castrum*, a toponym meaning “the fortified base of a Roman legion,” as noted by Wikipedia. According to the same school publication, in the Middle Ages *castrum* referred to any settlement that was not the seat of a bishopric. Piran was such a place, unlike, for example, Trieste, Novigrad, Poreč and Pula, which were considered cities because they had bishoprics. At the end of the first millennium, *de Castro* was not yet a surname but simply meant an inhabitant of a *castrum* (Romanello et al., 1998).



Figure 3. Coat of arms of the *de Castro* family in the Municipal Palace in Piran.

1.3. *De Castro's education, work and legacy*

As states Rosanna Panelli (Panelli, 2000) on the website “Diego de Castro,” he spent his childhood in his hometown until the age of nine, where he began attending primary school. The family later moved to their villa in Savudrija. He completed secondary school in Trieste and graduated in law from the University of Rome. Soon afterward, he became an assistant at the Faculty of Law in Rome and also attended a school of statistics. After completing his studies, he began teaching statistics at various Italian universities until he became a full professor in Turin. In Turin, he founded the Institute of Statistics, which was later named after him.

As stated on the aforementioned website (Panelli, 2000), during the Second World War, he participated in the preparation of a peace plan and spent some time in England. For many years, he dealt with the issue of Italy’s eastern border and published his reflections on the subject in the book “The Problem of Trieste” (1952). That same year, he was appointed Italy’s diplomatic representative in London—where he became a member of the Royal Statistical Society—and in Washington. As a leading expert on the Trieste question, he later published five books and numerous articles on the topic. After two years of diplomatic service, he returned to teaching at the University of Turin and later in Rome. Altogether, he taught for more than half a century. For his work, he received several recognitions in Italy and abroad, and after his retirement, the Italian President appointed him Professor Emeritus.

According to his wishes, *de Castro* is buried in the family tomb in the Piran cemetery (**Figure 4**). In his will, he left his library to Piran, consisting of 4200 books and around 10000 volumes of publications, mostly scientific journals in the field of statistics. The library is kept at the Italian Community “Giuseppe Tartini” in Piran. (Panelli, 2000).



Figure 4. tomb at the cemetery in Piran, where Diego de Castro is buried. In the background, a view of the sea. Diego de Castro wrote about the Piran cemetery (de Castro, 2003) that it is the “most beautiful cemetery,” from which one can see the “most beautiful panorama I have seen on the four continents I have visited.”

2. Diego de Castro and music

2.1. *De Castro's experience with music*

As Branka Preden writes in her master's thesis (Preden, 2015: 30), Diego de Castro played the violin as a child. Later in his life, however, he did not enjoy attending concerts, as music “moved him too deeply” (Preden, 2015: 30). As Branka Preden further notes, de Castro encouraged and financially supported all of his daughters' cultural interests. According to Preden (Preden, 2015: 74), he also contributed funds for the restoration of the organ in the Church of St. George in Piran.

2.2. *De Castro's thoughts abouts music*

De Castro wrote beautifully about music. In a letter addressed to the people of Piran shortly before his death (de Castro, 2003), written in response to an invitation to the opening ceremony of the primary school that would thereafter bear his name, he reflected on Giuseppe Tartini and on the phenomenon of music in general. As he wrote, the people of Piran should be proud of their town also because of Tartini's magnificent music, which made the town known around the world.

The letter from de Castro to the people of Piran, enlarged to poster size and exhibited at the Primary School “Vincenzo e Diego de Castro,” (**Figure 5**) concludes with the author's wish that all the people of Piran love one another regardless of their origin (De Castro, 2003).



Figure 5. Biographies of Diego and Vincenzo de Castro and a letter by Diego de Castro (on the right), Primary School “Vincenzo e Diego de Castro”.

De Castro stated that “music is the only art that unites all peoples.” (de Castro, 2003). He further substantiates this idea by explaining that “people, regardless of race, language, place of residence, or level of cultural understanding, can, through modern audio technology, listen to music at the same moment throughout the world—from Europe to Africa, from America to Australia and Asia. Millions, billions of people can, wherever they may be and at any moment, enjoy Tartini’s music” (de Castro, 2003).

2.2.1. Musical experience in the contemporary anthropology

The experience of music can therefore be accessible at the same moment anywhere in the world. Among the leading contemporary anthropologists who contributed to modern anthropological theory of experience are Victor Turner and Clifford Geertz (Throop, 2003). The perception and phenomenology of musical experience were examined in detail by Harris Berger (Berger, 2013), who explored how meaning can be found and created in music, and how situation and the broader cultural context influence the meaning people find in culture. Among other findings, Berger concluded that the formation of experience is not strictly a personal matter—although individuals exercise partial control over it, culture plays a crucial role. As further emphasises Berger (Berger, 2013), social context is also crucial: our ability to follow a particular dimension of musical structure largely depends on our previous experiences with music and on our formal and informal musical education.

3. Conclusions

A statistician, lawyer, diplomat, professor and author of numerous books and articles, Diego de Castro remains present in the memories of many residents of Piran, especially older members of the Italian community. In his hometown of Piran, an Italian-language primary school is named after him, allowing new generations to become acquainted with him. The Primary School “Vincenzo e Diego de Castro” is also attended by children of foreign immigrants, including several Russians and Ukrainians. Diego de Castro in his letter written for the school’s opening conveyed the message that all residents of his native town should love one another regardless of their origin. He encouraged the people of Piran to be proud of their town, in which the great musician Giuseppe Tartini was born. Of all the arts, de Castro stated, it is music that unites different people across the globe, since today it is possible to broadcast and hear music simultaneously anywhere in the world.

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Research

From TES (Techne, Episteme, Sophia) to STEAM: A Note

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Abstract:

This paper argues that contemporary STEAM education (Science, Technology, Engineering, Arts, Mathematics), while widely studied in pedagogical and policy terms, lacks a deeper epistemic foundation. It proposes the ancient Greek framework of Techne, Episteme, and Sophia (TES), drawn from Plato and Aristotle, as a philosophical structure for understanding STEAM. The author reconstructs TES as a dual-axis model: a vertical axis of cognitive depth (from practical skill, to theoretical knowledge, to reflective wisdom) intersecting with the horizontal axis of STEAM disciplines. This model suggests that all STEAM fields operate simultaneously across all three levels, yet modern education tends to prioritize techne and episteme while neglecting sophia—wisdom concerning the good of the whole. Through examples in medicine, architecture, and artificial intelligence, the paper shows how TES helps address ethical and governance questions that purely technical frameworks cannot resolve. It also revisits educational ideas in Plato and Aristotle to compare approaches to curriculum and formation. The paper concludes that TES is a useful analytical tool for rethinking education's purpose and structure, and proposes extending it to a four-part framework—Techne, Episteme, Phronēsis, and Sophia (TEPS)—as a direction for future research.

Keywords: Techne; Episteme; Sophia; STEAM; Plato; Aristotle

1. Introduction

This paper presents a brief overview of a recent larger study of Papanikos (2026) which examines how ancient Greek philosophy can help explain and strengthen modern educational models, especially STEAM, which stands for Science, Technology, Engineering, Arts, and Mathematics. STEAM has become an influential framework because it promotes interdisciplinary learning, creativity, innovation, and problem-solving. However, this study argues that modern educational systems often focus mainly on technical ability and measurable outcomes while paying less attention to the deeper purpose of knowledge and the ethical responsibilities that come with it. For this reason, the study turns to the ancient Greek framework of TES: *Techne*, *Episteme*, and *Sophia*.

Rather than presenting TES and STEAM as opposing systems, the study suggests that they should be understood as complementary. STEAM identifies important academic and professional disciplines, while TES explains different forms or levels of knowledge that can exist within any discipline. Through this combination, education can move beyond training students only to perform tasks and instead help them become thoughtful, responsible, and wise contributors to society.

2. The Meaning of TES

The first concept in the framework is *techne*. In ancient Greek thought, *techne* refers to practical skill, craft, or the ability to make and do things effectively. It is knowledge expressed through action and experience. In the modern world, *techne* can be seen in engineering design, coding, laboratory techniques, medical procedures, architecture, and artistic production. It answers the question of how something is done.

The second concept is *episteme*, meaning theoretical or scientific knowledge. *Episteme* is concerned with explanation, reasoning, and truth that can be demonstrated or justified. Mathematics, scientific laws, economic theories, and philosophical arguments all belong to this category. While *techne* focuses on practice, *episteme* focuses on understanding why things work and what principles govern them.

The third and highest concept is *sophia*, usually translated as wisdom. *Sophia* goes beyond skill and beyond information. It involves sound judgment, reflection on values, awareness of consequences, and orientation toward the common good. Wisdom asks not only whether something can be done, but whether it should be done. It connects knowledge with ethics and human flourishing.

According to this study, one of the greatest weaknesses of many modern systems is that they emphasize *techne* and *episteme* but neglect *sophia*. Students may graduate with strong technical skills and specialized knowledge, yet still lack the ability to use those abilities responsibly.

3. TES and STEAM as Complementary Models

A central argument of the paper is that TES and STEAM operate on different dimensions. STEAM describes fields of study, whereas TES describes forms of knowing. When combined, they create a richer educational model in which each discipline can contain skill, theory, and wisdom (Table 1).

In science, students need practical research methods and laboratory competence, which belong to *techne*. They also need theories, evidence, and logical explanation, which belong to *episteme*. Yet science also raises questions about environmental responsibility, human experimentation, and the social use of discoveries. These concerns require *sophia*.

The same pattern appears in engineering. Engineers must know how to build systems and solve technical problems, but they must also understand mathematics, materials, and physical principles. Beyond this, they need wisdom to consider safety, sustainability, accessibility, and the long-term effects of their designs on society.

The arts provide another example. Artistic creation requires technique and discipline, but it also includes theory, history, and criticism. At the highest level, art invites reflection on beauty, meaning, identity, and the human condition. In this sense, the arts naturally connect all three dimensions of TES.

Table 1. TES–STEAM Matrix (Analytical Projection).

	Science	Technology	Engineering	Arts	Mathematics
Techne	Experimental practice and instrumentation	Tool-building, coding, and system implementation	Design, fabrication, and construction practices	Craft, performance, and material production	Symbolic computation, algorithmic technique, and formal proof
Episteme	Theoretical modelling of natural laws and causal explanation	System architecture, design principles, and technical knowledge	Formal design theory, optimization, and structural analysis	Art theory, aesthetics, and critical interpretation	Abstract structures, formal systems, and logical foundations
Sophia	Discernment of what scientific knowledge means for the good as a whole	Responsible innovation and the governance of technological power for the good as a whole	Design for the Good and the human consequences of built systems	Cultivation of meaning, beauty, and shared human understanding	Reflection on the nature of truth, infinity, and the limits of formal reasoning

This model shows that no discipline should be reduced to technical training alone. Every field benefits when practice, theory, and wisdom are developed together.

4. Applications in Professional Life

The relevance of the TES framework becomes even clearer in professional contexts such as medicine, architecture, and artificial intelligence.

In medicine, doctors and nurses need practical competence in diagnosis, treatment, and procedures. They also depend on scientific knowledge of anatomy, disease, and pharmacology. However, healthcare constantly involves ethical choices: fairness in access to treatment, respect for patient autonomy, end-of-life decisions, and compassionate care. Technical success without wisdom would be insufficient.

Architecture also reflects the three dimensions. Architects require practical design skills and knowledge of construction methods. They must understand engineering principles, materials, and spatial planning. Yet buildings also shape communities, influence daily life, and express cultural values. A structure may be efficient and safe, but if it ignores human needs or destroys the surrounding environment, it lacks wisdom.

Artificial intelligence may be the most urgent modern example. AI depends on programming expertise and advanced scientific knowledge, but its development also raises serious concerns about privacy, bias, accountability, employment, and the future relationship between humans and machines. This study emphasizes that responsible AI cannot be achieved through technical progress alone. It also requires ethical reflection and wise governance.

5. Plato, Aristotle, and the Purpose of Education

The paper also draws on the educational ideas of Plato and Aristotle. Plato viewed education as a journey from opinion toward truth and ultimately toward the Good. In his ideal system, subjects such as mathematics and dialectic trained the mind for higher understanding. Education was not simply preparation for work, but preparation for wise leadership and just citizenship.

Aristotle offered a more practical and empirical perspective. He accepted the importance of skill, scientific knowledge, and wisdom, but he also emphasized *phronesis*, or practical wisdom. *Phronesis* is the ability to make good decisions in concrete situations where rules alone are not enough. This idea is especially valuable in modern professions, where individuals must respond to uncertainty, complexity, and competing values.

For this reason, the study suggests expanding TES into TEPS: *Techne*, *Episteme*, *Phronesis*, and *Sophia*. Such a model recognizes that education should not only teach knowledge and ideals, but also cultivate judgment in real-life situations.

6. Implications for Modern Education

The study offers important lessons for schools and universities today. First, wisdom should not be isolated in a single ethics course. Instead, ethical reflection and social responsibility should be integrated into every discipline. Second, curricula should balance practical training with theoretical depth, so that students understand both how to act and why they act. Third, professional education should include mentorship, case studies, and reflective practice in order to develop judgment. Finally, education should prepare learners not only for employment, but also for citizenship, cooperation, and responsible participation in a rapidly changing world.

7. Conclusions

This paper demonstrates that ancient Greek thought remains highly relevant to contemporary education. STEAM provides an important map of modern disciplines, but TES offers a deeper understanding of what it means to know. Skill and scientific knowledge are essential, yet they are incomplete without wisdom. In an age shaped by technological change and global challenges, societies need citizens and professionals who can think critically, act competently, and judge wisely. The integration of TES and STEAM therefore offers a stronger vision of education for the future.

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Research

From Sky Patterns: Hipparchus' Stars Bridge – İznik & Salerno STEAM Hackathon for Astronomy Education

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Abstract:

Within the framework of the Women Science Teachers initiative, the Sky Patterns: Hipparchus' Stars Bridge Between İznik and Salerno STEAM hackathon was implemented between September and November 2025. The project integrates the legacy of ancient astronomy with contemporary STEAM (Science, Technology, Engineering, Art, and Mathematics) education. Inspired by Hipparchus of Nicaea (c. 190–120 BCE), often regarded as the father of scientific astronomy, the project aimed to foster data literacy, inquiry-based learning, collaborative problem-solving, and cross-cultural interaction. The hackathon involved twenty one students aged 11–17 from Türkiye (Istanbul, Kocaeli) and Italy (Salerno). Participants explored astronomical patterns while examining the historical and aesthetic connections between İznik tiles and Italian ceramic traditions. Following training in project management, art history, augmented reality (AR), virtual reality (VR), artificial intelligence (AI), 3D modeling, and coding, students developed original interdisciplinary projects.

Additionally, students from three schools—Beşiktaş Anatolian High School (Istanbul), De Sanctis High School (Salerno), and Yeni Levent Anatolian High School (Istanbul)—contributed to the organization of the hackathon and supported peer learning processes.

A mixed-methods research design was employed, including pre- and post-assessments, student product evaluation rubrics, and semi-structured interviews. The findings indicate that integrating historical scientific heritage with digital technologies contributes to enhancing students' critical thinking, creativity, interdisciplinary understanding, and digital production skills.

Keywords: STEAM education; Hackathon pedagogy; astronomy education; Hipparchus; İznik tiles–Italian ceramics; interdisciplinary learning

1. Introduction

İznik is a multi-layered archaeological settlement that has hosted different civilizations since prehistoric times and has been included in the UNESCO World Heritage Tentative List since 2014. Owing to its rich collection of archaeological remains, monumental structures, and cultural heritage assets, the city represents an important center for cultural and religious tourism (Kapuci & Cengiz, 2023). Consequently, İznik provides a rich context for interdisciplinary STEAM activities that connect science, technology, engineering, art, mathematics, and cultural heritage.

Nicaea (modern-day İznik) occupies a significant place in the history of astronomy as the birthplace of Hipparchus. Astronomy and mathematics have historically played a fundamental role in shaping scientific thought and human understanding of the universe. Hipparchus of Nicaea, who lived in the second century BC, is widely recognized as one of the pioneers of scientific astronomy due to his systematic star catalogues and his use of trigonometric calculations. His approach can be considered an early form of data organization and pattern recognition, which are essential components of modern scientific analysis (Dreyer, 1953).

Recent research based on multispectral imaging has revealed new evidence of Hipparchus' lost star catalogue, demonstrating that his observations achieved an accuracy within one degree and were recorded using an advanced equatorial coordinate system, centuries before later astronomical catalogues (Gysembergh et al., 2022).

Beyond its scientific significance, İznik is also renowned for its ceramic heritage, which represents one of the most significant artistic achievements of the Ottoman Empire. Through cultural and commercial exchanges between the Ottoman Empire and Europe, Iznik ceramics influenced Italian maiolica production, particularly through decorative motifs and ceramic forms such as tondino dishes. These interactions demonstrate the important role of Iznik as a centre of artistic and cultural exchange between Anatolia and Europe (Zidan, 2019).

Building upon this historical foundation, the project titled Sky Patterns: Hipparchus' Stars Bridge Between İznik and Salerno was developed to establish a connection between ancient scientific knowledge and contemporary digital technologies. The project aims not only to integrate astronomy with modern educational tools but also to provide a holistic examination of a city through scientific, artistic, and technological perspectives. The cultural and scientific relationship established between İznik and Salerno contributes to the international dimension of the study and highlights the importance of interdisciplinary and cross-cultural learning environments (Graham, 2013).

Furthermore, the integration of artificial intelligence, augmented reality, virtual reality, and three-dimensional modeling tools into the educational process has created a dynamic and interactive learning environment. This interdisciplinary approach reflects the transition from STEM to STEAM education by incorporating artistic elements. STEM Education is an approach to learning that uses Science, Technology, Engineering and Math as access points for guiding student inquiry, dialogue, and critical thinking, and STEAM builds on this by integrating the Arts, science and culture into educational process (Kralj-Iglič & Istileulova, 2025).

2. Material and Methods

The project was implemented between September and November 2025 within the framework of the Women Science Teachers initiative and involved twenty-one students aged 11–17 from Türkiye (Istanbul and Kocaeli) and Italy (Salerno). The implementation was designed as a STEAM-oriented hackathon integrating scientific inquiry, digital production, cultural heritage, and collaborative problem-solving. Participants represented three schools (**Table 1**).

Table 1. Participating schools and student distribution.

School	Country	Level	Grade(s)	Female	Male	Total
IC Moscati-Fonseca Middle School	Italy	Middle School	8	4	4	8
Etiler Anatolian High School	Türkiye	High School	10–11	4	-	4
Kartepe Ertuğrul Gazi Anatolian High School	Türkiye	High School	9-10	6	3	9

The pedagogical design was based on inquiry-based STEAM education. As noted by Abdi (2014), inquiry-based science education engages students in the activities and thinking processes used by scientists to generate new knowledge. Likewise, Land (2013) emphasised that innovation emerges through the integration of technology with creative thinking and design. These principles formed the conceptual basis of the Sky Patterns project, which connected astronomy, cultural heritage, digital technologies, and artistic expression within a single interdisciplinary learning environment.

The project aimed to establish connections between the astronomical legacy of Hipparchus of Nicaea and the cultural heritage of İznik and Salerno through collaborative STEAM-based learning experiences. The learning programme began with preparatory sessions delivered by university academics, museum experts, participating teachers, and project mentors from Türkiye and Italy.

The programme included project management, the astronomical contributions of Hipparchus, cultural heritage, İznik tiles, Italian ceramic traditions, and emerging digital technologies. Digital technology training covered artificial intelligence (AI), augmented reality (AR), virtual reality (VR), extended reality (XR), coding, and three-dimensional (3D) modelling, with contributions from the University of Salerno, Bursa Uludağ University, and the STEAM Coordination Unit of the Istanbul Provincial Directorate of National Education. Museum specialists introduced the artistic and historical characteristics of İznik tiles and Italian ceramics, enabling students to compare the two cultural traditions. Training sessions were delivered in English, Turkish, and Italian to facilitate international collaboration.

Following the preparatory phase, students worked collaboratively in interdisciplinary teams to develop projects exploring the scientific, technological, artistic, and cultural dimensions of İznik. Throughout the project, they investigated astronomical concepts, cultural heritage, artistic patterns, and digital applications while designing their own interdisciplinary products. A peer-learning and mentoring model was integrated into the implementation, with four mentor students supporting teamwork, facilitating discussions, assisting in the use of digital technologies, and promoting communication among participants. Participating teachers provided continuous pedagogical guidance throughout the project.

The completed projects were presented during an international online dissemination event attended by students, teachers, academics, mentors, and invited experts from the participating countries.

Data were collected at the end of the hackathon using a mixed-methods approach. Quantitative instruments included a 28-item STEAM Interdisciplinary Awareness Scale, a Digital Technology Competency Test comprising ten multiple-choice questions and five performance tasks, a 20-item Hackathon Process Experience Scale, and an analytic product evaluation rubric assessing scientific accuracy, interdisciplinary integration, digital competence, aesthetic quality, and innovation. Qualitative data were obtained through semi-structured interviews exploring students' perceptions of STEAM integration, digital technologies, cultural heritage, teamwork, and project outcomes.

Quantitative data were analysed using descriptive statistics, while qualitative interview responses were examined thematically to identify common patterns related to student engagement, interdisciplinary understanding, digital competence, cultural heritage awareness, and learning experiences.

Participation was voluntary. Students and their families were informed about the educational objectives of the project, and informed consent was obtained for participation, data collection, and dissemination of educational outputs.

Within the framework of the project, mentor students conducted a comprehensive STEAM-based analysis of the city of İznik, transforming it into a multidimensional learning environment (Figure 1A).

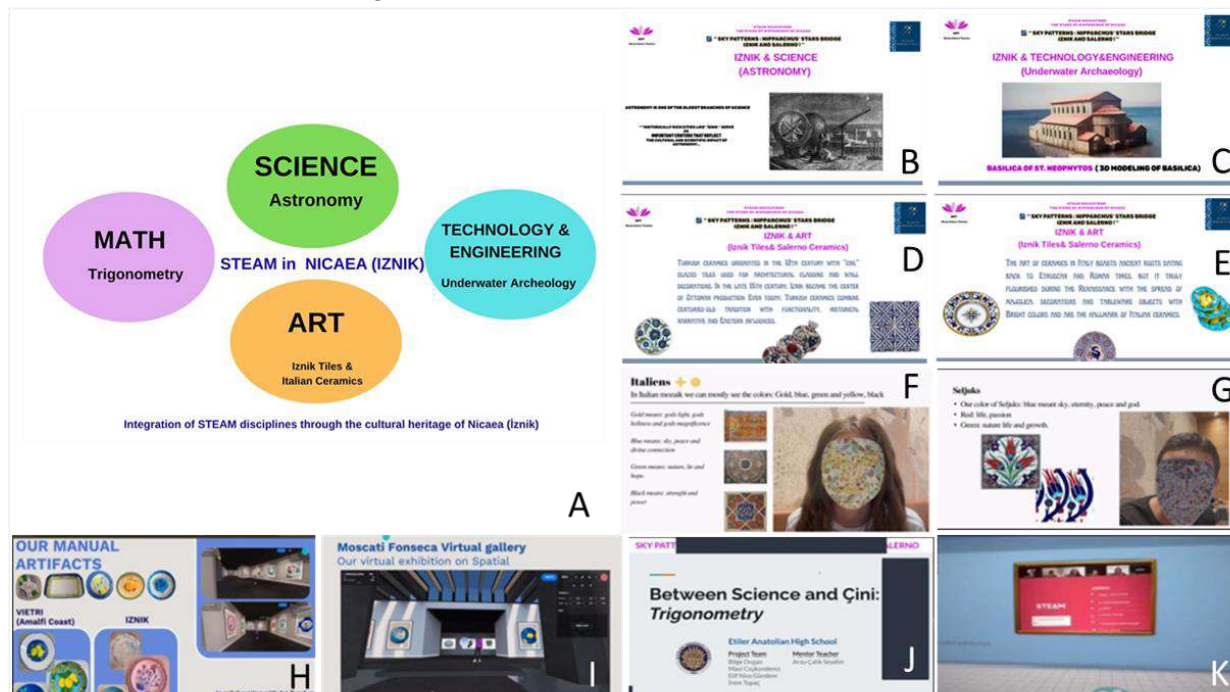


Figure 1. A: Conceptual STEAM model of Nicaea (İznik); B: Scientific heritage in İznik: The legacy of Hipparchus; C: Engineering in İznik: St Neophytos Basilica; D: Art in İznik: Ceramic heritage; E: Mathematics in İznik: Trigonometry; F,G: student presentations on stellar distance measurement through parallax and the comparison of İznik and Italian ceramic traditions, highlighting integration of astronomy, mathematics, cultural heritage and design within a STEAM learning environment; H,I: exploring color symbolism and digital pattern design in Italian and İznik art; J,K: illustration of integration of mathematics, digital technologies and visual communications within the STEAM framework. Panels B-K were frame-grabbed from the online presentations.

From a scientific standpoint, the study was grounded in the astronomical legacy of Hipparchus, including his work on star catalogues, celestial navigation, and observational astronomy (Figure 1B). In the domains of technology and engineering, students explored advanced digital applications such as AR, VR, and 3D modeling, exemplified through the reconstruction of the Basilica of St. Neophytos, alongside investigations into underwater technologies, AI-assisted surveying processes, geomatics engineering, geology, seismology, and sonar systems (Figure 1C). From an artistic perspective, the rich aesthetic tradition of İznik tiles was analysed and comparatively examined alongside Italian ceramics, focusing on geometric patterns, symmetry, composition, colour palettes, and symbolic meanings (Figures 1D). In the mathematical dimension, students applied concepts of trigonometry, geometry, astronomical calculations, and ratio-based pattern analysis to interpret both scientific and artistic structures (Figure 1E).

This interdisciplinary approach enabled students to perceive İznik not only as a historical and cultural site, but also as a dynamic intersection of science, mathematics, technology, and art. Furthermore, the integration of artificial intelligence, augmented reality, virtual reality, and three-dimensional modeling tools into the educational process has created a dynamic and interactive learning environment. As Bequette and Bequette (2012) noted, STEAM education integrates science, technology, engineering, arts, and mathematics while emphasizing creativity, design thinking, and interdisciplinary learning. This inter-

disciplinary approach reflects the transition from STEM to STEAM education by incorporating artistic elements into scientific inquiry, thereby enhancing both analytical thinking and creative production skills.

Figure 1A developed within the project, representing the interdisciplinary integration of astronomy, underwater archaeology, cultural heritage (Iznik tiles and Italian ceramics), and trigonometry. The model reflects a holistic approach to place-based.

3. Results

The educational intervention resulted in a multidimensional STEAM learning environment that integrated astronomy, cultural heritage, digital technologies, engineering, mathematics, and art. The results indicate that this interdisciplinary approach enhanced students' learning outcomes and supported the development of critical thinking, creativity, and digital competences. This interdisciplinary approach reflects the transition from STEM to STEAM education by incorporating artistic elements into scientific inquiry, thereby enhancing both analytical thinking and creative production skills.

Figure 1 illustrates the educational outcomes of the STEAM intervention. From a scientific perspective, students explored the astronomical legacy of Hipparchus, including his work on star catalogues, celestial navigation, and observational astronomy (**Figure 1B**). Within the technology and engineering components, students applied AR, VR, AI, and three-dimensional (3D) modelling to the reconstruction of the Basilica of St Neophytos and investigations of underwater archaeology, geomatics engineering, geology, seismology, and sonar systems (**Figure 1C**). From an artistic perspective, they compared the aesthetic traditions of Iznik tiles and Italian ceramics, examining geometric patterns, symmetry, composition, colour palettes, and symbolic meanings (**Figure 1D**). Within the mathematical component, students applied trigonometry, geometry, astronomical calculations, and proportional pattern analysis to interpret both scientific and artistic structures (**Figure 1E**). **Figure 1A** was developed within the project and presents a conceptual STEAM model integrating astronomy, underwater archaeology, cultural heritage (Iznik tiles and Italian ceramics), and trigonometry. The model illustrates a holistic place-based learning approach that connects scientific inquiry with cultural heritage and digital technologies.

This interdisciplinary approach enabled students to perceive Iznik not only as a historical and cultural site, but also as a dynamic intersection of science, mathematics, technology, and art. Furthermore, the integration of artificial intelligence, augmented reality, virtual reality, and three-dimensional modeling tools into the educational process has created a dynamic and interactive learning environment. **Figure 1A** developed within the project, representing the interdisciplinary integration of astronomy, underwater archaeology, cultural heritage (Iznik tiles and Italian ceramics), and trigonometry. The model reflects a holistic approach to place-based.

Students demonstrated notable levels of critical thinking, interdisciplinary connection, and digital production skills, reflecting the effectiveness of the STEAM-based hackathon model.

Table 2. Analytical Product Evaluation Rubric Results (Students, n = 21)

Dimension	Description	Score	Percentage
Scientific Accuracy	Correct use of astronomy and mathematics concepts	81/105	77.1%
Interdisciplinary Integration	Balanced integration of STEAM components	105/105	100%
Digital Technical Competence	Effective use of 3D modeling, AR, and AI tools	105/105	100%
Aesthetic Quality	Design quality and visual integrity	77/105	73.3%
Innovation	Originality and creativity of project outputs	105/105	100%
Total		473/525	90.1%

Each criterion was scored on a five-point scale ranging from 1 (Beginning) to 5 (Excellent).

The rubric results indicate that students successfully integrated astronomy, mathematics, cultural heritage, and digital technologies into their project outputs. Particularly high scores in interdisciplinary integration, digital competence, and innovation demonstrate the

effectiveness of the STEAM-based hackathon model in fostering creative and technology-enhanced learning.

The digital outputs produced by the participants included three-dimensional models, augmented and virtual reality environments, animated visual content, and virtual exhibitions. These outputs illustrate the ability of students to transform abstract astronomical data into meaningful visual and cultural representations, thereby bridging the gap between scientific knowledge and creative expression.

All n=21 participants attended a hackathon for the first time, and all students expressed willingness to participate in similar activities in the future. This finding indicates a highly positive learning experience and suggests that the STEAM-based hackathon model successfully promoted student engagement, motivation, and interest in interdisciplinary learning.

Table 3. Students' Hackathon Participation Experience (n = 21).

School	Students (Female/Male)	First-Time Hackathon Participants	Willing to Participate Again
IC Moscati-Fonseca Middle School	8 (4F, 4M)	8 (100%)	8 (100%)
Etiler Anatolian High School	4 (4F, 0M)	4 (100%)	4 (100%)
Kartepe Ertuğrul Gazi Anatolian High School	9 (6F, 3M)	9 (100%)	9 (100%)
Total	21	21 (100%)	21 (100%)

Qualitative interview findings further supported the quantitative results. Students most frequently identified the integration of science and art as the strongest connection among STEAM disciplines. Participants reported that digital tools accelerated their learning process and enhanced their engagement with project activities. The historical scientific legacy of Hipparchus was perceived as inspiring and relevant for future projects. Students highlighted collaboration and teamwork as important factors contributing to project success, while the virtual museum was frequently mentioned as the project output of which they were most proud. Furthermore, all interviewed students expressed their willingness to participate in similar international STEAM projects in the future.

The implementation conducted at IC Moscati – Fonseca Middle School in Salerno focused on integrating cultural heritage with digital production through both manual and computational approaches. The exploration of Hipparchus' star catalogue enabled students to link astronomical knowledge with coordinate systems and spatial representations. (Figures 6). Furthermore, the development of Python-based digital tiles intended for execution in the Astro Pi environment demonstrated the integration of coding, astronomy, and artistic design within a unified STEAM framework. Students developed three-dimensional models of İznik and Salerno ceramics using block-based coding and created digital content combining ceramic traditions with elements of local culture.

In addition, they utilized the Europeana digital archive to design animated visual content, thereby connecting historical artifacts with contemporary digital storytelling (Figure 7).

The implementation at Kartepe Ertuğrul Gazi Anatolian High School emphasized the integration of mathematical reasoning, astronomy, and artificial intelligence. Inspired by Hipparchus' trigonometric methods, students constructed geometric models and visualized celestial relationships through angles and spatial measurements. Artificial intelligence tools were employed to analyze facial structures and generate personalized İznik tile patterns, illustrating the intersection of data analysis, digital art, and cultural heritage (Figures 8-9). Additionally, the recreation of Eratosthenes' experiment through a narrative-based approach enabled students to understand complex scientific concepts such as the calculation of the Earth's circumference in an accessible and engaging manner.

Students from Etiler Anatolian High School applied concepts of trigonometry and geometry to explore the relationships between mathematical structures, artistic design, and digital technologies. Through the use of artificial intelligence-supported modeling tools, they

investigated how geometric principles can be transformed into visual and three-dimensional representations. The resulting digital artefacts were presented within a virtual exhibition environment, providing opportunities to examine the integration of mathematics, design, and digital communication within a STEAM-based learning framework (**Figures 1J,K**).

4. Discussion

As Bequette and Bequette (2012) noted, STEAM education integrates science, technology, engineering, arts, and mathematics while emphasizing creativity, design thinking, and interdisciplinary learning. The findings indicate that the integration of cultural heritage, astronomy, and digital technologies within a STEAM-based hackathon provides an effective interdisciplinary learning environment. The high overall rubric score (90.1%), together with the maximum scores obtained for interdisciplinary integration, digital competence, and innovation, demonstrates that students successfully combined scientific, artistic, and technological knowledge in their project outputs.

These findings are consistent with previous studies emphasizing the value of STEAM education in fostering creativity, interdisciplinary thinking, and problem-solving skills (Bequette & Bequette, 2012). Similarly, the inquiry-based structure of the hackathon supported active learning and knowledge construction, in line with the principles described by Abdi (2014). The effective use of AI, AR, VR, and 3D modelling tools also supports Land's (2013) view that innovation emerges through the integration of technology and creative thinking.

An additional indicator of success was student engagement. All participants were first-time hackathon attendees, and 100% expressed willingness to participate in similar activities again, suggesting a highly positive learning experience. Furthermore, the collaboration between students from Türkiye and Italy promoted intercultural learning and strengthened the connection between scientific and cultural heritage education.

However, the study was limited by its relatively small sample size, the use of descriptive statistics only, and the absence of inferential statistical analyses and comprehensive quantitative comparisons. These limitations restrict the generalizability of the findings. Future studies should involve larger participant groups, employ pre- and post-assessments, and incorporate more rigorous statistical analyses to further validate the effectiveness of STEAM-based hackathon models.

5. Conclusions

The Sky Patterns: Hipparchus' Stars Bridge Between İznik and Salerno project presents an innovative and scalable educational model that integrates astronomy, cultural heritage, and advanced digital technologies within a STEAM framework. The findings demonstrate that artificial intelligence-supported learning environments can significantly enhance student engagement, creativity, and interdisciplinary understanding.

The project highlights the potential of cultural heritage as a powerful educational resource, capable of connecting historical knowledge with contemporary technological practices. The international collaboration between İznik and Salerno further emphasizes the importance of cross-cultural learning and global educational exchange.

Furthermore, the project contributed to the promotion of gender equality in STEAM education. By ensuring balanced participation of girls and boys, the hackathon created an inclusive learning environment where female students could actively contribute to scientific and technological activities. In particular, the online format enabled girls from different socio-economic and geographical backgrounds to connect with international peers and collaborate on shared project outputs. These opportunities supported not only interdisciplinary learning but also the empowerment of girls as active participants in science, technology, and innovation.

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Healthy Ageing in the Silver Economy: Lifelong Learning as a Driver of Future Skills

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Abstract:

Population ageing has become one of the defining global transformations of the twenty-first century, influencing healthcare, education, labour markets, technological innovation, and economic development. According to recent demographic projections, the global population aged 65 years and over is expected to nearly double, increasing from approximately 703 million in 2023 to 1.5 billion by 2050. These demographic trends have accelerated the development of the Silver Economy, creating new challenges and opportunities for sustainable economic development.

This paper examines the relationship between healthy ageing, the Silver Economy, lifelong learning, and changing labour-market dynamics. It argues that healthy ageing extends beyond healthcare to encompass cognitive well-being, digital inclusion, social participation, and continuous competence development. Furthermore, the paper proposes a lifelong learning competence framework that integrates the knowledge, skills, and capabilities required to support healthy ageing, longevity, employability, and active participation in the Silver Economy.

Drawing on selected examples from Asian countries, the paper examines how Asian policy approaches promote healthy ageing, lifelong learning, and the Silver Economy. Particular attention is given to the implications of digitalisation, artificial intelligence, demographic change, and economic uncertainty for lifelong learning and workforce participation. The paper also discusses interdisciplinary educational approaches, including experiential learning, design thinking, and narrative-based STEAM learning, as examples of fostering digital, creative, and social competences across the life course. It concludes that investing in lifelong learning is a strategic investment in human capital that promotes healthy ageing, supports longevity, strengthens the Silver Economy, enhances intergenerational knowledge transfer, and contributes to resilient, inclusive, and sustainable labour markets.

Keywords: Demographic change; Healthy ageing; Labour market; Lifelong learning competences, STEAM, Silver economy

1. Introduction

1.1 Population Ageing Trends and Silver Economy

The world is approaching a demographic turning point as the global population aged 65 years and over is projected to nearly double by 2050, increasing from 703 million in 2023 to 1.5 billion. At the same time, the population aged 80 years and over is expected to exceed 300 million by 2030, more than doubling from 143 million in 2020 (Worldmetrics, 2026).

Population ageing has become one of the defining demographic transformations of the twenty-first century. During the past five decades, average life expectancy in Europe has increased by approximately 15–20 years, while persistently declining fertility rates have fundamentally reshaped the continent's age structure. According to demographic projections, individuals aged 65 years and over are expected to represent nearly 40% of the European population by 2080. These demographic changes have profound economic implications. As populations age, governments, businesses, and labour markets must adapt to changing patterns of consumption, employment, healthcare, innovation, and social participation. Statistics of world population by broad age groups, 1950–2100 (United Nations population estimates, 2024) demonstrates the same trends (see **Figure 1**). Purple line (65+ years) on Figure 1 is illustrating the global trend of population ageing. Regarding the share of older people (65+) in the total EU population, **Table 1** (below) demonstrates that Italy (24.7%), Portugal (24.3%) and Bulgaria (24.0%) had the highest shares.

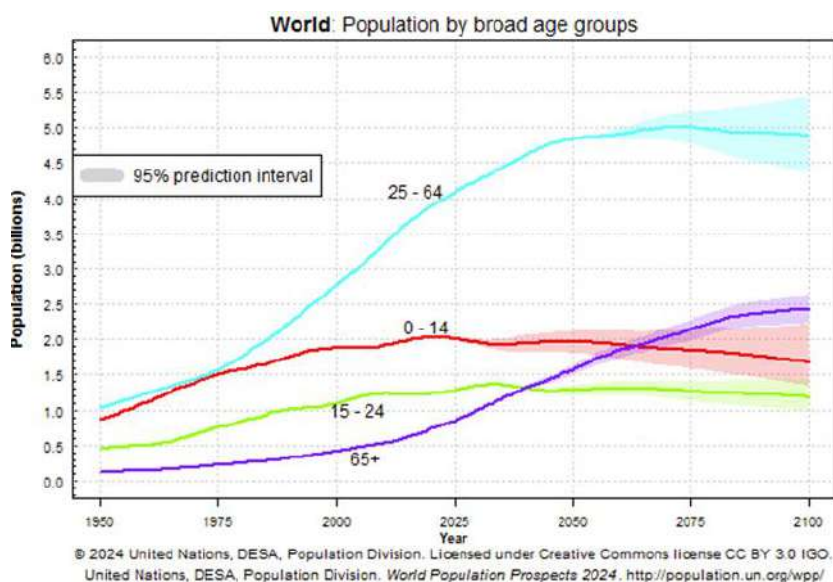


Figure 1. World population by age groups, 1950–2100 (UN, 2024). The UN figure illustrates estimates (1950–2023) and projected population trends (2024–2100) for four age groups worldwide: (red 0–14 year), green: 15–24), and purple: 65 and over. Light blue line (25–64 years) represents the working-age population, which remains the largest age group. Purple line (65+ years) shows the fastest growth among all age groups, illustrating the global trend of population ageing.

This demographic transition has given rise to the concept of the Silver Economy. The earliest precursor to the Silver Economy was the Japanese concept of the Silver Market (Silver Shijō), which emerged during the 1970s in response to rapid population ageing and referred primarily to products and services designed for older consumers. Building on this concept, the European Commission (2018) defined the Silver Economy similarly as "the sum of all economic activities that serve the needs of people aged 50 and over..." (see 3. Definition of Silver Economy).

As demographic ageing accelerates, the Silver Economy extends far beyond social policy and healthcare. It is reshaping labour markets, patterns of consumption, technological innovation, and economic growth. Consequently, the concept has evolved from a market-oriented approach focused primarily on products and services for older consumers to a broader economic framework that recognises the needs, capacities, and contributions of older adults. Realising the potential of the Silver Economy depends on enabling older adults to remain healthy, active, and socially engaged. In this context, the World Health Organization (WHO, 2020) defines healthy ageing as "the process of developing and main-

taining the functional ability that enables well-being in older age." The concept of "functional ability" refers to the capabilities that enable people to meet their basic needs, learn, grow and make decisions, remain mobile, build and maintain relationships, and contribute to society.

Table 1. The population of the EU member states on January 1, 2025

	0-14 years old			15-64 years old			65-years old or over		
	2015	2024	2025	2015	2024	2025	2015	2024	2025
EU ⁽¹⁾⁽²⁾	15.3	14.6	14.4	65.6	63.8	63.6	19.1	21.6	22.0
Belgium	17.0	16.3	16.1	64.9	63.8	63.7	18.1	19.9	20.2
Bulgaria	13.9	14.1	14.0	65.6	62.1	62.0	20.5	23.8	24.0
Czechia	15.2	15.9	15.5	67.0	63.6	63.8	17.8	20.5	20.7
Denmark	17.0	15.7	15.5	64.4	63.6	63.6	18.6	20.7	20.9
Germany	13.2	13.9	13.9	65.8	63.7	63.4	21.0	22.4	22.7
Estonia ⁽²⁾	15.9	16.0	15.6	65.3	63.5	63.5	18.8	20.5	20.9
Ireland	21.4	18.9	18.5	65.7	65.6	65.8	12.9	15.5	15.7
Greece	14.5	13.1	12.8	64.6	63.6	63.5	20.9	23.3	23.7
Spain	15.1	13.2	12.9	66.5	66.4	66.4	18.4	20.4	20.7
France ⁽¹⁾	18.6	17.0	16.6	63.0	61.5	61.5	18.4	21.5	21.9
Croatia	14.7	14.0	13.8	66.3	63.0	62.9	19.0	23.0	23.3
Italy	13.8	12.2	11.9	64.3	63.5	63.4	21.9	24.3	24.7
Cyprus	16.2	15.3	15.2	69.3	67.0	66.5	14.5	17.7	18.3
Latvia	15.0	15.6	15.1	65.6	63.1	63.0	19.4	21.3	21.9
Lithuania	14.5	14.5	14.1	66.9	65.2	65.0	18.6	20.3	20.9
Luxemburg	16.7	15.7	15.7	69.1	69.3	69.1	14.2	15.0	15.2
Hungary	14.5	14.5	14.3	67.7	64.8	64.8	17.8	20.7	20.9
Malta	14.4	12.3	12.1	67.6	69.3	69.5	18.0	18.4	18.4
Netherlands	16.7	15.1	15.0	65.5	64.4	64.2	17.8	20.5	20.8
Austria	14.3	14.4	14.3	67.2	65.8	65.5	18.5	19.8	20.2
Poland ⁽¹⁾	15.0	15.1	14.8	69.6	64.4	64.2	15.4	20.5	21.0
Portugal	14.4	12.8	12.6	65.2	63.1	63.1	20.4	24.1	24.3
Romania ⁽¹⁾	15.5	15.9	15.4	67.5	64.1	64.3	17.0	20.0	20.3
Slovenia	14.8	14.7	14.5	67.3	63.5	63.4	17.9	21.8	22.1
Slovakia	15.3	16.0	15.8	70.7	65.6	65.4	14.0	18.4	18.8
Finland	16.4	14.9	14.6	63.7	61.7	61.8	19.9	23.4	23.6
Sweden	17.3	17.1	16.8	63.1	62.3	62.4	19.6	20.6	20.8
Iceland	20.4	18.3	17.9	66.1	66.1	66.2	13.5	15.6	15.9
Lichtenstein	15.1	14.4	14.2	68.9	65.3	65.1	16.0	20.3	20.7
Norway	18.0	16.4	16.1	65.8	64.9	64.9	16.2	18.7	19.0
Switzerland	14.9	15.0	14.8	67.3	65.7	65.7	17.8	19.3	19.5
Montenegro	18.5	18.2	18.0	67.8	65.1	64.8	13.7	16.7	17.2
Moldova	17.9	17.5	:	71.2	65.1	:	10.9	17.4	:
North Macedonia	16.8	16.6	16.4	70.5	65.3	65.0	12.7	18.1	18.6
Georgia	17.4	19.5	19.2	68.7	64.3	64.2	13.9	16.2	16.6
Albania	19.0	:	15.2	68.6	:	63.6	12.4	:	21.2
Serbia	14.4	14.4	14.4	67.1	63.2	62.9	18.5	22.4	22.7
Turkye	24.3	21.4	20.9	67.7	68.4	68.5	8.0	10.2	10.6
Ukraine	15.1	:	:	69.3	:	:	15.6	:	:

(¹) 2025 provisional/estimated; (²) Break in time series in various years between 2015 and 2025. (:) Not available. Source: Eurostat (online data code: demo_pjanid). Population is estimated as 450.6 million people (Eurostat, 2025). People of working age (15 to 64 years) is 63.6% of the population. Older people (aged 65 years and over) had a 22.0% share. In 2025, compared with 2024, the share of older people increased in 26 EU countries, and only Malta had a constant share.

The objective of this paper is to examine how demographic ageing interacts with technological transformation and changing labour-market dynamics, and to demonstrate that the Silver Economy should be recognised as an important driver of sustainable economic de-

velopment. The paper argues that lifelong learning is a key enabler of healthy ageing, supporting the development of lifelong learning competences and future skills that enable older adults to remain economically active, socially engaged, and adaptable throughout longer working lives. It further demonstrates that continuous learning and intergenerational knowledge exchange are essential for strengthening labour-market resilience, fostering innovation, and promoting inclusive and sustainable economic growth.

2. Reconceptualising the Silver Economy

The European Commission (2018) defines the Silver Economy as "the sum of all economic activity that serves the needs of people aged 50 and over, including the products and services they purchase directly and the further economic activity this spending generates." The report further states that this definition is "consistent with an earlier definition developed by Oxford Economics. "This conceptualisation primarily adopts a demand-side perspective, emphasising the needs, consumption patterns, and purchasing power of older adults.

While this definition has provided an important foundation for understanding the economic implications of population ageing, it places comparatively less emphasis on the productive capacities, accumulated knowledge, and continuing contributions of older adults to economic and social development. Furthermore, the age threshold of 50 years reflects primarily a policy and market-segmentation approach rather than the concept of functional ageing, which emphasises individuals' capabilities, health status, and capacity to participate actively in economic and social life. In contemporary longevity societies, chronological age is becoming an increasingly limited indicator of an individual's productive capacity, employability, learning potential, creativity, and social participation.

Thus, the present study reconceptualises the Silver Economy as an inclusive economic, social, and learning ecosystem that recognises and supports the capabilities, experience, and contributions of individuals throughout longer and healthier lives. Rather than being defined by chronological age, the Silver Economy should be understood as a framework that enables individuals to remain healthy, productive, employable, and socially engaged across the life course.

From this perspective, the Silver Economy should not be understood solely as a response to the growing needs of an ageing population. Equally important is recognising older adults as a strategic source of human capital whose accumulated knowledge, professional expertise, institutional memory, and lifelong learning represent valuable economic assets. Through decades of professional practice, older adults acquire tacit knowledge, professional judgement, leadership capacity, problem-solving abilities, and mentoring skills that are difficult to replace or replicate. These assets represent a form of accumulated human capital that becomes increasingly valuable in knowledge-intensive and innovation-driven economies. They contribute significantly to organisational resilience, innovation, intergenerational knowledge transfer, and sustainable economic development. Rather than defining individuals primarily by chronological age, the Silver Economy should recognise and utilise their capabilities, experience, and continuing potential to create economic and social value throughout longer and healthier lives.

One of the greatest challenges facing ageing societies is not population ageing itself, but the loss of accumulated human capital resulting from the early or mandatory withdrawal of experienced professionals from active employment. In many countries, retirement policies and labour-market practices lead to the departure of highly qualified professionals whose tacit knowledge, professional judgement, leadership, and mentoring capacity cannot easily be replaced. At the same time, younger generations contribute complementary strengths, including digital fluency, openness to technological innovation, and new perspectives. Sustainable labour markets therefore require mechanisms that facilitate intergenerational knowledge transfer, enabling the complementary strengths of different generations to be integrated rather than substituted. Such an approach not only preserves organisational knowledge but also strengthens innovation, resilience, and long-term economic competitiveness.

Over the past decade, the concept of (the) Silver Economy has evolved considerably beyond its original consumer-oriented perspective. Contemporary research increasingly recognises older adults not only as consumers but also as producers, innovators, entrepreneurs, mentors, volunteers, and active contributors to economic and social development.

This broader understanding reflects a paradigm shift from viewing population ageing primarily as a demographic challenge towards recognising longevity as a strategic resource for innovation, human capital development, and sustainable economic growth.

Accordingly, this paper conceptualises the Silver Economy as an inclusive economic, social, and learning ecosystem that enables individuals to remain healthy, productive, employable, and socially engaged throughout longer lives. It recognises older adults not only as consumers but also as creators of economic and social value through their knowledge, experience, innovation, entrepreneurship, lifelong learning, and intergenerational knowledge transfer. Within this framework, lifelong learning competences constitute the enabling mechanism through which future skills are continuously developed, supporting healthy longevity, lifelong employability, labour-market resilience, active participation, and sustainable economic development. Thus, the Silver Economy should not be understood merely as an economy serving older people; rather, it is an economy that values longevity, lifelong learning, accumulated human capital, and intergenerational knowledge exchange as strategic drivers of innovation, resilient labour markets, inclusive economic growth, and sustainable development.

3. Healthy Ageing Policy Strategies in Selected Asian Countries

Compared with the EU, several Asian countries have adopted more explicit national strategies linking population ageing with digital innovation, preventive healthcare, active ageing, and longevity. **Table 2** therefore presents selected Asian strategies that illustrate how ageing is being framed as a national policy priority across health, technology, and social participation. According to the United Nations World Population Prospects 2024, Hong Kong and its neighbouring economies in the East Asia region are ageing rapidly, with South Korea heading towards being one of the world's oldest economies. South Korea's population aged 65 and above is projected to be nearly 40% by 2050, according to the United Nations, compared to just over 20% in 2025. By then, Hong Kong (46.4%), South Korea (39.7%), Taiwan (38.7%) and Japan (37.5%) will be the top four economies globally with the oldest populations.

Table 2. Selected national strategies on healthy ageing and longevity in Asia

Country	National strategy (source)	Main objective
Japan	Society 5.0 (Society 5.0 (Cabinet Office, Government of Japan; 2016; 6th STI Basic Plan, 2021; Integrated Innovation Strategy 2025)	Promotes a human-centred digital society using AI, IoT, robotics & digital innovation to address societal challenges: population ageing and improve quality of life
Singapore	Action Plan for Successful Ageing (Ministry of Health, Singapore, 2024)	Promote active ageing, lifelong learning, employment, health & community participation throughout later life.
South Korea	Fourth Basic Plan for an Aging Society and Population (2021–2025), Presidential Committee on Aging Society and Population Policy. (2020).	Promotes healthy and active ageing through integrated health&long-term care, employment, pension reform, dementia care, community support, and the development of Age-Tech, AI, robotics and digital health& the Silver Economy.
Vietnam	National Strategy for the Elderly to 2035, a Vision to 2045 (Prime Minister's Decision: 383/QĐ-TTg, 2025)	Promotes healthy, active, and dignified ageing through preventive healthcare, family and community support, social participation & age-friendly environments.

4. Megatrends and Life-long learning competences

The megatrends presented in **Table 3** are adapted from the World Economic Forum's Future of Jobs Report 2025, which identifies technological change, geoeconomic fragmentation, economic uncertainty, demographic shifts, and the green transition as the principal drivers of labour-market transformation. To align with the focus of this paper, the technological change dimension is specified as digitalisation and artificial intelligence, while demographic shifts are examined through the lens of population ageing and the development of the Silver Economy.

Table 3. Five megatrends shaping the labour market by 2030 and lifelong learning competencies for the silver economy.

Megatrend	Main impact on the labour market	Lifelong learning competencies for the silver economy
Technological change (Digitalisation & Artificial Intelligence)	Automation, digital transformation, emergence of new occupations, reskilling	Digital literacy, AI literacy, data management, cybersecurity awareness, continuous ICT upskilling, adaptation to emerging technologies, STEAM competences fostering creativity
Economic uncertainty	Productivity optimisation, organisational restructuring, changing employment patterns	Adaptability, resilience, financial literacy, entrepreneurial thinking, problem-solving, project management, STEAM-based innovation, and design thinking,
Green transition	Growing demand for green jobs and sustainable production	Green skills, environmental awareness, sustainable resource management, circular economy competencies, energy efficiency, STEAM competences supporting sustainability, eco-innovation, and systems thinking.
Demographic shifts (ageing)	Labour shortages, longer working lives, increased demand for health and care services, active ageing	Lifelong learning, health literacy, mentoring, intergenerational knowledge transfer, leadership, communication, age-friendly digital skills, lifelong learning, and intergenerational learning across the life course
Goeconomic fragmentation	Supply-chain restructuring, strategic autonomy, changing global trade patterns	Cross-cultural communication, language skills, international collaboration, systems thinking, risk management, supply-chain resilience, STEAM competences supporting innovation, adaptability, and global problem-solving.

Taken together, these megatrends suggest that future labour-market resilience will depend not only on technological adaptation but also on lifelong learning competences that support healthy ageing, workforce participation, and the development of the Silver Economy. **Table 3** illustrates that the five megatrends identified by the World Economic Forum have important implications for lifelong learning and workforce development. Digitalisation and artificial intelligence are transforming occupations and increasing demand for advanced digital competences, while the green transition is creating new employment opportunities requiring sustainability-related knowledge and skills. At the same time, demographic ageing and labour shortages highlight the importance of health literacy, intergenerational knowledge transfer, age-inclusive employment policies, and continuous competence development. These developments reinforce the need for a lifelong learning competence framework that supports healthy ageing, employability, and active participation in the Silver Economy.

5. Conclusions

Population ageing is transforming demographic structures, economic activity, and labour markets worldwide. Rather than representing a burden on public finances, older adults constitute an increasingly valuable source of human capital, experience, innovation, and purchasing power.

Healthy ageing should therefore be regarded not merely as a health objective but as the fundamental precondition for developing the Silver Economy. By maintaining functional ability, employability, and social participation throughout longer lives, healthy ageing enables older adults to continue contributing to economic growth, innovation, and sustainable development. Achieving these outcomes, however, depends on continuous lifelong learning that equips individuals with the knowledge, skills, and competences required to adapt to technological change, extend working lives, and participate actively in the Silver Economy. Interdisciplinary educational approaches, including STEAM, experiential learning, and design thinking, provide important mechanisms for developing these competences across the life course.

The development of the Silver Economy coincides with profound technological changes driven by artificial intelligence, automation, and digitalisation. Together, these trends are reshaping employment patterns and creating demand for new competencies, flexible working arrangements, and continuous workforce upskilling.

Future labour-market resilience will depend on policies that promote active ageing, retain experienced workers, facilitate intergenerational knowledge transfer, and support continuous skills development. Recognising the economic potential of older adults will

therefore be essential for achieving sustainable growth, social inclusion, and long-term competitiveness in ageing societies.

This paper proposes a lifelong learning competence framework for developing the future knowledge, skills, and competences required in the Silver Economy.

The framework integrates cognitive, digital, health-related, creative, cultural, and intergenerational competences that enable individuals to remain healthy, employable, resilient, and socially engaged throughout longer lives and extended working careers. It argues that the future resilience of labour markets will depend not only on digital and AI-related skills but also on continuous lifelong learning that supports healthy ageing, employability, creativity, cultural participation, and intergenerational knowledge exchange.

Thus, this paper makes two principal contributions. First, it reconceptualises the Silver Economy as an inclusive economic, social, and learning ecosystem that recognises older adults not merely as consumers but as active contributors to human capital, innovation, entrepreneurship, and sustainable economic development. Second, it proposes a lifelong learning competence framework for developing the future knowledge, skills, and competences required in the Silver Economy. The framework integrates cognitive, digital, health-related, creative, cultural, and intergenerational competences that enable individuals to remain healthy, employable, resilient, and socially engaged throughout longer lives and extended working careers.

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Research

Rethinking Ordinary Object in Contemporary Painting Creation

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Abstract:

This paper focuses on exploring the creation of contemporary painting based on an ordinary object, namely the human back (the rear part of the body). Rethinking the ordinary object in the creation of contemporary painting amid global geopolitical currents filled with tensions, and even open warfare, has become highly relevant. The ordinary object explored in this creative practice is grounded in the credo of Arts-Based Research (ABR), as proclaimed by Leavy (2015). The credo of research-based creation prioritizes the exploration and discovery of the ordinary object—the human back—precisely to reflectively present various social themes. The depiction of the "human back," or what is called Rückenfigur, is not only open to representing social themes but also visually challenges the diametrical view between the "front" and the "back." The face, chest, and so on are regarded as the front part of the body, while the back, hips, and so on are referred to as the rear. In the exploration of this ordinary object, however, the rear part of the human body is instead positioned as the front, because it becomes the sole subject matter of the painting, thereby dissolving the distinction between the "front" and the "back." This depiction of the ordinary object—the "back"—is ingeniously explored through drawings using Chinese ink and ballpoint pen, thus possessing artistic strength that supports the originality of this choice in re-evaluating the ordinary object in the creation of contemporary painting.

Keywords: Contemporary Painting, Ordinary Object, human back theme, Art-Based Research

1. Introduction

1.1. Creative challenges

Contemporary painting always offers a countercurrent to the tendency toward the pragmatist orientation of everyday life. When the world faces conflicts, even open warfare as it has recently, the creativity of artists is challenged to enter into new possibilities and propositions, in order to read the current situation reflectively.

The creative challenge in reading the situation reflectively is so that the contemporary paintings created subsequently remain relevant and possess historical significance. When artistic exploration is eroded amid such upheavals, the possibility is precisely that art becomes merely banal and jargonistic. The history of modern art in the 1940s, for example, in the midst of the turmoil of World War II, saw painters in America, some of whom were migrant painters from Europe, give birth to the school of Abstract Expressionism, which visually did not depict the war, but rather unleashed pure emotion, which subsequently shook the world's consciousness regarding the meaning of freedom.

Considering these creative issues, over the past two years the author has undertaken excavation and exploration by rethinking the ordinary object as a thematic choice. The decision to rethink the ordinary object aims to discover an authentic visual language that is reflectively relevant in reading the current social situation.

The selection of a specific ordinary object continued through experimentation and by evaluating the subject matter of previous paintings that the author had explored over nearly thirty years. From 2017 to 2022, exploration and creative research were conducted to reinterpret an ancient artifact in Bali, namely the Yeh Pulu relief. This creative re-search sought to discover an artistic concept as well as a method of creation, in which the relief was re-read through, among other approaches, the methods of recasting and reframing. The artistic relief was not merely repainted; rather, the relief object was presented in a new way by composing it alongside other relevant objects, such as various iconic destinations around the world, for example, placing the figurative forms of the Yeh Pulu relief in front of the Sydney Opera House in Sydney, Australia.

In the creative research of rethinking the ordinary object, the author explored the "human back." The subject matter of the "back" (Rückenfigur) is used to speak about anything, including reflections on the current social situation. The artistic technique continues to combine the line-drawing technique that the author developed in 2006 with a formulation of abstraction in the background. The exploration of the theme of the ordinary object continues, with the development of the artistic findings achieved over the past two years.

1.2. Problems and Creative Propositions

The problem that arises in building the relevance and significance of contemporary painting by re-evaluating the ordinary object is the selection of an ordinary object that is particular and distinctive, while at the same time offering a reflection on contemporary social conditions. The exploration conducted over the past two years has succeeded in formulating the ordinary object, in the form of the "back" (Rückenfigur), as an authentic thematic and artistic representation.

2. Material and Methods

2.1. Artistic Medium

The exploration of contemporary painting based on rethinking the ordinary object requires the support of an artistic medium that is both unique and distinctive. In the exploration of the subject matter of the "back" in painting, the work is constructed through the formulation of Chinese ink drawing and ballpoint pen drawing, together with the expressiveness of acrylic color strokes. The drawing technique consists of repeated circular line scribbles, layered from thin to thick, which then form the figurative image of the human back, proportionally chosen with a stout body character. The combination of the subject matter of the "back" (Rückenfigur) with line drawing (drawing) is referred to as the reciprocal credo of drawing-fat-back imagery as a contemporary visual language (Adnyana, in Bayu Segara, 2025)

2.2. Creative Method

The creative method of contemporary painting with the subject matter of the "back" (Rückenfigur) is based on the creative credo of Arts-Based Research (ABR), as proclaimed by Leavy (2015). The research was conducted based on the exploration of contemporary

painting carried out in three stages, namely thematic study, artistic exploration, and the realization of the artwork. The thematic study began with an awareness of building the significance of the ordinary object in reading the broader social situation, which then led to the selection of the object matter of the "back" (Rückenfigur) in the form of a stout figurative image. In the next stage, the exploration of the object of the "back" was painted using line drawing (drawing) techniques and color abstraction in the background, so that artistically there is both continuity and renewal from the previously created "Yeh Pulu" series. The realization stage of the artwork constitutes a creative effort to form a unique visual expression while at the same time inviting thematic sensation, as it speaks reflectively about the current situation.

3. Results and Discussion

The results of the creative research in contemporary painting based on the exploration of the ordinary object, namely the "back" (Rückenfigur), encompass three aspects: the discovery of a specific thematic subject in the artworks; the reciprocal visual configuration of drawing-back imagery; and reflective aesthetics, which indicate the visual significance of contemporary painting in reading the social situation reflectively.

Contemporary painting based on rethinking the ordinary object in responding to creative challenges amid a broader social situation beset by conflict, and even war, has become highly relevant. The ordinary object is explored as far as possible in order to remain relevant and to creatively respond to the need for social representation in the practice of painting. Based on the creative credo of Arts-Based Research (ABR), the author carried out three stages of creation, namely thematic study, artistic exploration, and the realization of the artwork.

These three stages were undertaken simultaneously with the author's creative autonomy, drawing upon more than 30 years of experience in painting. The stage of formulating the theme was not only complemented by literary readings, recognizing that the subject of the artwork constitutes the fundamental character and identity of the artist, but also involved exploring possibilities for its development. The choice fell upon the visual object of the "back" (Rückenfigur). The subsequent stage involved artistic experimentation as the basis for representing the theme of the "back." The chosen approach was to formulate a drawing technique for depicting the subject matter and color abstraction as the background. The combination of drawing and abstraction is also compelling because it generates contrast while at the same time creating a dialogical fusion, as it is dynamically animated by the figurative image of a stout back. The relationship between drawing and the "stout back" occurs in a dynamic reciprocal manner. The depiction of a figure from behind represents a desire to reveal and conceal it at the same time. This is a sign of consciousness (Couteau, 2026).

The process of realizing paintings with the subject matter of the "back" (Rückenfigur) continues to stimulate the author's enthusiasm and passion in the effort to form a new configuration. For example, the artwork entitled *Peace and Reason* (**Figure 1**), measuring 180 × 180 cm, executed in ink and acrylic on canvas, 2026, depicts the figurative image of a stout back, with the arms crossed behind the back holding a rifle, while the right hand is raised with the fingers signaling the code for peace, namely the index and middle fingers forming the "peace" symbol. Viewed from the position of the depicted back, both the hand holding the rifle and the hand making the "peace" gesture appear in front (clearly visible). If one follows the conventional logic that the face, chest, and so forth constitute the front of the body, then the rifle held in the left hand would not be visible at all because it would be concealed by the body. The depiction of *Peace and Reason* in this painting is highly satirical and invites social reflection on the intersection of "Peace and Reason."



Figure 1. Contemporary painting by the author, entitled "Peace and Reason", size 180x180 cm, ink and acrylics on canvas, 2026.

In the artwork entitled Balloon Boy (**Figure 2**), measuring 180 × 180 cm, executed in ink and acrylic on canvas, 2026, the figurative image of a stout back is depicted, with the left hand clenched in a fist crossing behind the back, and the right hand holding two balloons. The stout body appears to be floating through the air. A dragon tattoo is inscribed on the right side of the back. In a cynical and ironic reading, the stout, tattooed body, seemingly strong and invincible, is in fact easily carried away by the balloons. The balloons may serve as an anecdotal code related to gossip, empty talk, or discourse in the social sphere.



Figure 2. Contemporary painting by the author, entitled "Balloon Boy", size 180x180 cm, ink and acrylics on canvas, 2026.

Over the past three years, experimentation with the subject of the "back" (Rückenfigur) in a stout figurative form has produced more than a dozen authentic contemporary paintings. This series of works, entitled Panggung Punggung ("Back Stage"), has been exhibited in various reputable international events, including Art Moment Jakarta and Art Jakarta in 2025. The contemporary painting series Panggung Punggung was also exhibited at the Bali-Global Art Map Exhibition (B-GAME), as part of the Bali-Global Axis of Arts and Design (B-GAAD) II, 2025, at the Agung Rai Museum of Art and Komaneka Art Gallery, Ubud. The work Peace and Reason was exhibited at Art Moment Jakarta on 5–7 June 2026, while Balloon Boy was exhibited at Yogya Gallery, Yogyakarta, in late May 2026. The painting of "back" series also chosen be as ilustration of short story titled "Maling Buku", in english "book thief" written by Eko Darmoko, was publised on 11 April, 2026 at Kompas news paper.

Thematically and artistically, this contemporary painting with the subject matter of the "back" can serve as a creative vehicle for connecting aesthetics with the current social situation in a reflective manner. Thematically, this contemporary painting also remains open to further exploration so that it may become increasingly relevant and possess greater historical significance.

5. Conclusions

This creation research, based on the credo of Arts-Based Research (ABR), has succeeded in identifying the urgency of the ordinary object in connecting the relevance of artistic creativity with broader social issues. This research has also succeeded in formulating the figurative image of the "back" (Rückenfigur) as a vehicle for artistic creative exploration based on drawing and color abstraction. The relationship between drawing and the imagery of the stout back is dynamically reciprocal, because artistically the drawing constrains the object, while abstraction liberates it, creating a dynamic visual order further connected by the choice of the stout back, which conveys a humorous impression.

The relevance of the discovered subject matter of the "back" (Rückenfigur) lies in its ability to reveal and represent broader social issues in both a satirical and reflective manner. This relevance demonstrates that artworks read the spirit of the times reflectively, rather than in a jargonistic manner, as is often the case with political discourse.

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The Wizard of Oz

at  sphere



Research

International Collaborative STEM Learning in Early Childhood Education through eTwinning Projects within the Erasmus+ Framework

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Abstract:

This paper presents a longitudinal educational research experience developed between 2020 and 2025 through four international eTwinning projects implemented annually with preschool children aged 4–6 years at Kindergarten with Extended Program Vinerea, Romania. The projects - *Coding STEAM and Stories*, *STEM Research in Kindergarten*, *Kindergarten from Home*, and *STEM with Pete is Really Great* - were carried out in collaboration with educational institutions from Romania, Greece, Turkey, Lithuania, and Poland within the eTwinning community, part of the Erasmus+ framework. Each project received both the National Quality Label and the European Quality Label, demonstrating educational quality, innovation, and international impact. The study explores the integration of STEM methodology, inquiry-based learning, coding activities, storytelling, collaborative digital learning, and intercultural communication in early childhood education. Findings indicate significant contributions to creativity, communication, collaboration, problem-solving, computational thinking, and intercultural awareness among preschool children.

Keywords: eTwinning; Erasmus+; STEM education; Preschool education; Inquiry-based learning; Coding

1. Introduction

1.1. *Introduction and Pedagogical Foundation*

The rapid transformation of contemporary education requires innovative pedagogical approaches capable of preparing children for the technological and interdisciplinary challenges of the twenty-first century. STEM education (Science, Technology, Engineering, and Mathematics) has gained increasing importance in early childhood education because it promotes curiosity, creativity, communication, critical thinking, and problem-solving through experiential and inquiry-based learning (Bybee, 2013). Research has also demonstrated that age-appropriate STEM activities can support the development of computational thinking and scientific reasoning from the preschool years (Papadakis, 2021).

Beginning in 2020, Kindergarten with Extended Programme Vinerea (Romania) implemented a series of annual international eTwinning projects focused on STEM education for preschool children aged 4–6 years. These projects were developed within the eTwinning framework, a European initiative supporting collaboration among educational institutions, and contributed to the broader objectives of the Erasmus+ programme related to innovation, digital education, inclusion, and intercultural cooperation (European Commission, 2023).

The projects involved educational institutions from Romania, Greece, Turkey, Lithuania, and Poland and promoted collaboration among teachers, children, and families through digital communication and joint educational activities. Four projects were implemented during the study period: STEM, Coding STEAM and Stories, STEM Research in Kindergarten, Kindergarten from Home, and STEM with PETE is Really Great. Each project addressed specific educational objectives while sharing a common focus on STEM-based learning.

The projects aimed to promote STEM education through inquiry-based and experiment-based learning, encouraging children to observe, explore, formulate questions, and discover scientific concepts through hands-on activities adapted to their developmental level. Another objective was to strengthen cooperation between kindergarten and families by actively involving parents in educational activities, including the continuation of classroom experiments and STEM tasks at home.

In addition, the projects integrated storytelling into STEM education by connecting narratives with experiments, engineering challenges, coding activities, and creative problem-solving tasks. This approach was intended to increase children's motivation and engagement while supporting the development of creativity, communication skills, collaboration, computational thinking, and critical thinking. Through international collaboration and the use of digital tools, the projects also sought to foster intercultural awareness and digital competences among both children and teachers.

This paper presents the pedagogical implementation of these international STEM projects and examines their contribution to children's learning experiences, family participation, and international educational collaboration in early childhood education.

2. Research Design and Methods

This study employed a qualitative research design based on longitudinal pedagogical observation conducted throughout the implementation of four annual international eTwinning STEM projects between 2020 and 2025. The educational activities were documented through continuous classroom observations, children's learning products, teachers' reflective notes, and records of family participation. The collected evidence was analysed qualitatively to identify patterns related to children's engagement, creativity, collaboration, communication, problem-solving, and early computational thinking.

The educational intervention was supported by a wide range of materials and digital resources that facilitated inquiry-based learning, experimentation, coding activities, storytelling, engineering challenges, and collaborative learning.

The materials included:

- STEM experiment kits adapted for preschool education;
- recyclable materials for engineering and construction activities;
- sensory materials for scientific observation and exploration;
- magnets, water containers, measuring cups, pipettes, balloons, plants, seeds, ice, colours, and other natural materials used in experiments;
- simple robotics and coding resources suitable for early childhood education;

- digital platforms and collaborative tools, including Padlet, Canva, Wordwall, LearningApps, and TwinSpace;
- tablets, interactive whiteboards, digital presentations, and online collaborative activities;
- storytelling resources and thematic educational games;
- complete sets of *Pete the Cat* books used in the project *STEM with PETE is Really Great*
- story cards, sequencing cards, emotion cards, and other visual supports;
- worksheets, posters, lapbooks, and collaborative classroom displays;
- art and craft materials, including markers, coloured paper, glue, cardboard, paint, and modelling materials;
- home-made experimental materials prepared by children together with their families;
- educational videos, digital quizzes, and collaborative online presentations.

These resources supported active, hands-on learning and enabled the integration of STEM concepts with creativity, digital technologies, and family participation throughout the educational process.

The project implemented an interdisciplinary STEM/STEAM approach by integrating children's literature with inquiry-based and hands-on learning activities. Using *Pete the Cat* as a narrative context, learners engaged in a variety of educational tasks, including scientific experiments, problem-solving activities, introductory coding, engineering design challenges, creative arts activities, and collaborative learning experiences. This pedagogical framework was designed to connect storytelling with authentic learning situations, thereby supporting the development of conceptual understanding across multiple STEAM disciplines (Figure 1).



Figure 1. STEM with *PETE is Really Great* project. Examples of educational activities integrating the *Pete the Cat* stories are centered on the character Pete, a blue cat, with inquiry-based STEM/STEAM learning, including scientific experiments, coding, engineering design, and collaborative problem-solving. These books are used in preschool and early primary education because they combine simple narratives with themes of resilience, problem-solving, emotions, creativity, friendship, and learning.

3. Results

The implementation of the four international eTwinning STEM projects generated complementary learning experiences across different areas of preschool education. The project *Coding STEAM and Stories* engaged children in coding games, interactive narratives, and collaborative problem-solving activities that incorporated computational thinking, sequencing, creativity, and digital storytelling. Children constructed logical sequences, followed coding paths, and expressed ideas through stories linked to STEM challenges.

STEM Research in Kindergarten introduced inquiry-based learning through hands-on experiments involving water, magnets, plants, colours, measurement, and natural phenomena. Children participated in activities involving observation, prediction, experimentation, and logical reasoning while exploring scientific concepts appropriate for early childhood education.

During the COVID-19 pandemic, *Kindergarten from Home* adapted STEM education to online and home-learning environments. Parents participated as educational partners by conducting experiments and STEM activities together with their children, thereby maintaining continuity of learning and strengthening collaboration between families and teachers.

The project *STEM with Pete is Really Great* (Figure 1) integrated the children's book series *Pete the Cat* with engineering, coding, mathematics, and collaborative problem-solving activities. Using stories as a narrative context, children participated in scientific experiments, introductory coding activities, engineering design challenges, creative arts activities, and collaborative learning experiences. The project was awarded both the National Quality Label and the European Quality Label within the eTwinning programme.

Across all four projects, qualitative pedagogical observations conducted by participating teachers indicated high levels of children's engagement, communication, collaboration, creativity, curiosity, critical thinking, and early computational thinking. International co-operation among partner institutions from Romania, Greece, Turkey, Lithuania, and Poland also promoted intercultural awareness, digital competences, and professional collaboration among educators.

4. Discussion

The findings suggest that interdisciplinary STEM education can be effectively implemented in preschool settings through the integration of inquiry-based learning, storytelling, coding, engineering design, and collaborative activities. These observations are consistent with previous studies reporting that integrated STEM approaches support children's creativity, problem-solving abilities, and scientific thinking (Bybee, 2013; Margot & Kettler, 2019).

The findings suggest that computational thinking can be introduced successfully at the preschool level through developmentally appropriate, play-based experiences. This finding supports previous research showing that coding activities enhance young children's logical reasoning and problem-solving skills (Papadakis, 2021).

Storytelling emerged as an important pedagogical strategy by providing meaningful contexts for scientific exploration and engineering challenges. Integrating literature into STEM activities increased children's motivation and emotional engagement while facilitating connections between scientific concepts and everyday experiences.

Another important outcome was the active involvement of families, particularly during the COVID-19 pandemic. Home-based STEM activities strengthened communication between teachers and parents and extended children's learning beyond the classroom. At the same time, international collaboration through eTwinning encouraged the exchange of teaching practices and educational resources among partner institutions, contributing to teachers' professional development and the implementation of innovative educational approaches.

Although the study is based on qualitative pedagogical observations rather than standardised assessment instruments, the findings indicate that international STEM projects can provide meaningful learning experiences and promote innovation in early childhood education.

The study has several limitations. It is based on qualitative pedagogical observations conducted in a single preschool setting and does not include standardized measures of children's learning outcomes or a comparison group. Consequently, the findings should be interpreted as evidence of educational practice rather than causal proof of effectiveness.

5. Conclusions

The implementation of four international eTwinning STEM projects between 2020 and 2025 demonstrates the educational value of interdisciplinary STEM learning in preschool education. The projects supported the development of children's creativity, communication, collaboration, curiosity, critical thinking, and early computational thinking while strengthening family involvement and international educational cooperation.

The study also highlights the benefits of combining inquiry-based learning, storytelling, coding, engineering design, and digital collaboration to create engaging learning experiences for young children. International eTwinning partnerships facilitated professional exchange among teachers and contributed to the dissemination of innovative educational practices across participating countries.

Future studies should complement qualitative pedagogical observations with systematic assessment methods and quantitative measures to provide stronger evidence of the educational impact of STEM-based international collaboration in early childhood education.

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Conflicts of Interest: The authors declares no conflict of interest.

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Research

Air Art Retreats: Creative Wellbeing at the Intersection of Art, Psychology, and Education

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Abstract: In recent decades, the growing prevalence of psychological stress, social fragmentation, and identity-related challenges has intensified the need for integrative approaches to wellbeing. This is particularly evident among individuals with migration experiences, for whom processes of adaptation often involve emotional instability and disruption of social belonging. The Air Art Retreats initiative presents an interdisciplinary model that combines artistic practice, psychological insight, and educational methodology within natural environments. This article situates the initiative within existing research in art therapy, environmental psychology, and experiential learning. It argues that creative engagement in nature fosters emotional regulation, cognitive activation, and social cohesion, while also supporting identity reconstruction. Through a synthesis of theory and practice, the article demonstrates how artistic processes can function as transformative tools for individual and collective wellbeing.

Keywords: Art therapy; Wellbeing; Creativity; Migration; Environmental psychology; Experiential learning

1. Introduction

The relationship between creativity and human wellbeing has increasingly become a subject of scholarly attention across multiple disciplines, including psychology, neuroscience, education, and public health. Contemporary research consistently demonstrates that engagement in artistic activities contributes to emotional regulation, stress reduction, and overall improvements in mental health (Fancourt & Finn, 2019). These findings are particularly relevant in the context of modern societies, where individuals are frequently exposed to chronic stressors, digital overstimulation, and reduced opportunities for meaningful social interaction.

Within this broader context, the Air Art Retreats initiative emerges as a practice-based response to these challenges. Rather than approaching wellbeing through a single disciplinary lens, the initiative integrates artistic creation, psychological reflection, and educational engagement into a unified experiential format. Participants are invited to engage in plein air painting within natural settings, where attention to light, colour, and spatial composition becomes a means of reconnecting with the present moment.

The emphasis on present-moment awareness aligns with mindfulness-based frameworks, which highlight the role of attention and perception in stabilizing psychological states (Kabat-Zinn, 1990). However, unlike traditional mindfulness practices that often rely on meditation, Air Art Retreats employ artistic practice as the primary medium through which awareness is cultivated. This distinction is significant since it allows participants to access reflective states indirectly through action rather than introspection alone.

2. Theoretical foundations: nature, creativity, and human cognition

The effectiveness of plein air artistic practice can be understood through several complementary theoretical frameworks. One of the most influential is the Attention Restoration Theory, which proposes that exposure to natural environments restores cognitive capacities that are depleted through sustained directed attention (Kaplan & Kaplan, 1989). Urban environments demand constant cognitive control, whereas natural settings provide what Kaplan describes as “soft fascination,” allowing the mind to recover without effort. Simultaneously, the concept of flow developed by Mihaly Csikszentmihalyi offers insight into the psychological mechanisms underlying deep creative engagement. Flow is characterized by intense concentration, a sense of control, and intrinsic motivation (Csikszentmihalyi, 1990). Artistic practice, particularly in immersive environments, provides optimal conditions for entering this state.

From a neuroscientific perspective, creative activities have been shown to engage multiple brain networks associated with emotion, reward, and self-referential processing. Studies indicate that sustained artistic engagement can lead to measurable changes in brain structure and function, supporting the idea of neuroplasticity (Bolwerk et al., 2014). These findings suggest that creativity is not merely expressive but also transformative at a biological level.

2. Migration, identity, and the need for creative interventions

Migration represents a complex psychological and social process that extends far beyond physical relocation. Individuals undergoing migration frequently experience disruptions in identity, loss of social networks, and heightened levels of uncertainty. Research in cross-cultural psychology has consistently identified these factors as significant contributors to stress and reduced wellbeing (Bhugra, 2004).

The process of acculturation requires individuals to negotiate between multiple cultural frameworks, often leading to internal conflict and fragmentation of identity (Berry, 2005). Traditional verbal forms of support may not always be sufficient to address these challenges, particularly when emotional experiences are difficult to articulate.

In this context, creative practices offer an alternative mode of expression. As noted by Cathy Malchiodi, artistic processes enable individuals to externalize internal experiences through symbolic representation, facilitating emotional processing and integration (Malchiodi, 2012). This non-verbal dimension is especially valuable in intercultural settings, where language barriers and cultural differences may limit conventional communication.

The Air Art Retreats initiative initially focused on immigrant women, recognizing both the vulnerability and resilience of this group. By providing a supportive environment for creative expression, the retreats create conditions in which participants can explore and re-construct their sense of self.

4. Art education and the development of perception

Artistic practice within the Air Art Retreats is not conceived as mere spontaneous self-expression, but as a cultivated perceptual discipline grounded in the traditions of art education. At its core lies the idea that learning to see is neither passive nor immediate, rather, it is a trained, culturally mediated, and cognitively complex process. The act of painting outdoors becomes an exercise in perceptual refinement, where attention is gradually reoriented from habitual recognition toward nuanced observation (**Figure 1**).



Figure 1. Participant engaged in plein air painting. Direct observation of the landscape encourages focused attention, perceptual refinement, and the development of visual awareness.

Exposure to historical artistic movements plays a crucial role in this transformation. Movements such as Impressionism, for instance, fundamentally challenged the primacy of representation by shifting the artistic focus toward the fleeting qualities of light, atmosphere, and sensory experience. In this context, perception is no longer understood as the accurate depiction of objects, but as an active and interpretive engagement with reality. The work of Claude Monet exemplifies this shift, demonstrating how vision can be reconfigured into a dynamic process shaped by time, environment, and subjective presence. From an educational perspective, this approach aligns with the view that the arts cultivate distinctive modes of thinking. Eisner (2002) argues that artistic engagement develops cognitive capacities that extend beyond the scope of conventional academic disciplines. These include the ability to attend to subtle variations, to remain open in situations of uncertainty, and to construct meaning in the absence of fixed solutions. Such forms of thinking are particularly relevant in contemporary contexts characterized by complexity and ambiguity (Eisner, 2002).

Perception in this framework is not treated as an isolated visual skill but as an embodied and relational process. Participants do not simply observe the landscape; they inhabit it through sensory, emotional, and material interaction. The brushstroke becomes both a mark and a form of inquiry, translating perception into action. This resonates with broader theories of embodied cognition, which suggest that thinking emerges through engagement with the physical world rather than abstract reasoning alone. Within the retreats, art historical knowledge is introduced not as a rigid canon but as a living resource that participants can actively engage with. References to artistic traditions serve as points of orientation rather than prescriptions, enabling individuals to situate their own practice within a continuum of cultural production. This dialogical relationship between past and present enriches the creative process, fostering both a sense of belonging and a capacity for innovation. The integration of art education into the retreat structure transforms painting from a technical activity into a mode of inquiry. It invites participants to reconsider how they see, how they interpret, and how they relate to the world around them. In doing so, it

expands the scope of artistic practice from the production of images to the cultivation of perception itself.

5. The psychological dimension of creative practice

The psychological framework underpinning the Air Art Retreats extends far beyond the general notion of wellbeing, engaging instead with more nuanced processes of emotional regulation, self-awareness, and identity integration. Within this context, creative practice functions not simply as a mode of expression, but as a structured yet open-ended psychological space in which individuals can encounter, process, and reconfigure their internal experiences within a safe environment. Unlike direct verbal reflection, which may at times feel confrontational or limiting, artistic activity allows for an indirect mode of engagement, where emotions can be explored through metaphor, gesture, and material interaction. This indirectness is particularly significant in relation to emotional regulation. Contemporary psychological research suggests that symbolic and non-verbal forms of expression can facilitate access to affective states that are otherwise difficult to articulate (Malchiodi, 2012). Through the act of painting, participants externalize internal experiences, transforming diffuse or overwhelming emotions into visible and tangible forms. This process creates a critical distance that enables reflection without detachment, allowing individuals to both experience and observe their emotions simultaneously. In this sense, creative practice operates as a mediating space between inner experience and conscious awareness.

The motivational dynamics of this process can be understood through Self-Determination Theory, which identifies autonomy, competence, and relatedness as fundamental psychological needs (Deci & Ryan, 2000). The retreat environment is deliberately structured to support all three dimensions. Autonomy is fostered through the freedom to choose subject matter, pace, and style, enabling participants to retain a sense of agency over their creative process. Competence develops gradually through guided instruction and repeated engagement, allowing individuals to experience mastery and progression. Relatedness emerges within the shared creative environment, where participants work alongside others, witnessing and being witnessed in their process. This collective dimension is particularly important, as it transforms individual creativity into a relational experience, reinforcing a sense of belonging. At the same time the retreats also engage with deeper layers of cognition and embodiment. The theory of embodied cognition suggests that thinking is not confined to abstract mental processes but is fundamentally shaped by bodily interaction with the environment (Wilson, 2002). Therefore, painting, in this context, becomes a form of embodied thinking. The movement of the hand, the resistance of the brush against the canvas, and the shifting perception of colour and light all contribute to a dynamic feedback loop between perception and action. Cognition unfolds through doing, rather than preceding it.

Furthermore, the temporal dimension of creative practice plays a crucial role in its psychological impact. The sustained attention required for painting encourages a slowing down of cognitive processes, counteracting the fragmented attention patterns characteristic of contemporary digital life. This temporal shift supports deeper forms of concentration and presence, closely related to the psychological state of flow described by Mihaly Csikszentmihalyi. Within this state, self-consciousness diminishes, and individuals become fully immersed in the activity, leading to enhanced intrinsic satisfaction and psychological integration. (Csikszentmihalyi, 1990).

Importantly, the retreats also create conditions for what may be described as narrative reconstruction. Through repeated engagement in creative activity, participants begin to re-interpret their experiences and identities, not necessarily through explicit storytelling, but through evolving visual expressions. This process aligns with broader psychological theories that emphasize the role of meaning-making in wellbeing. Art, in this sense, becomes a medium through which individuals can reorganize their internal narratives, integrating past experiences with present perception. In sum, the psychological dimension of creative practice within Air Art Retreats is multifaceted, encompassing emotional, cognitive, motivational, and relational processes. By combining structure with openness, individual reflection with collective experience, and perception with action, the retreats establish a complex psychological ecosystem. Within this ecosystem, creativity is not an isolated skill but a mode of being one that supports resilience, self-understanding, and the ongoing negotiation of identity.

6. Structure and methodology of the retreat

The retreats are conducted in natural environments selected for their aesthetic and sensory qualities. Participants work outdoors, engaging directly with their surroundings (**Figure 2**). This direct engagement contrasts with studio-based practices, where observation is often mediated through photographs or memory.

The methodological approach is intentionally flexible. Some participants prefer structured instruction, while others gravitate toward intuitive exploration. By accommodating both approaches, the retreats create an inclusive environment that respects individual differences in learning styles. This dual approach reflects principles of constructivist learning theory, which emphasizes active participation in knowledge creation (Vygotsky, 1978; Kolb, 1984). Learning is not transmitted but constructed through interaction with the environment and others.



Figure 2. Landscape paintings produced during the Air Art Retreats and presented in an outdoor exhibition setting. The public display of participants' artworks encourages reflection, social interaction, and a sense of creative achievement.

7. Cognitive, emotional, and social outcomes

The outcomes observed in Air Art Retreats align with extensive empirical findings on the neurobiological benefits of creativity. Beyond general academic success (Catterall, 2009), specific research on adults demonstrates that visual art production enhances functional connectivity in the brain's default mode network, significantly increasing psychological resilience (Bolwerk et al., 2014). Furthermore, long-term artistic engagement has been shown to yield measurable improvements in memory and attention among older adults (Mahendran et al., 2018). These cognitive gains are amplified by the 'soft fascination' of natural environments, which facilitates stress recovery and replenishes depleted attentional resources (Ulrich et al., 1991).

Socially, the retreats foster a sense of belonging and community. Group creative activities have been shown to strengthen social bonds and promote cooperative behaviour (Tarr et al., 2014). For individuals with migration experiences, this sense of belonging is particularly significant, as it counteracts feelings of isolation. Participants frequently report increased self-efficacy, defined by Bandura (Bandura, 1997) as the belief in one's ability to achieve desired outcomes. This shift in self-perception is a critical component of resilience and long-term wellbeing.

8. Sustainability and broader impact

In addition to its psychological and educational dimensions, the initiative incorporates principles of environmental and cultural sustainability. Engagement with local landscapes encourages appreciation of natural and cultural heritage, aligning with frameworks promoted by UNESCO (UNESCO, 2013).

Sustainable practices, including the use of local materials and environmentally conscious logistics, reflect broader efforts to integrate ecological awareness into cultural activities (Sterling, 2001). By promoting offline, nature-based experiences, the retreats also address the growing impact of digital saturation on mental health.

9. Conclusions

Air Art Retreats represent a holistic model of creative wellbeing that integrates artistic practice, psychological insight, and educational methodology. By situating creative activity within natural environments and social contexts, the initiative offers a powerful framework for addressing contemporary challenges related to stress, identity, and social disconnection.

The interdisciplinary nature of the model allows it to function across multiple domains, including mental health, education, and cultural engagement. As such, it holds significant potential for further development and research, particularly in exploring the long-term impact of creative interventions on wellbeing.

Conflicts of Interest: The authors declare no conflict of interest.

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FROM HOUSEHOLD APPLIANCES TO MEDICAL DEVICES: THE ROLE OF RARE EARTH ELEMENTS IN MODERN TECHNOLOGY

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and Mathematics

RARE EARTH ELEMENTS (REE)

Lanthanum (La)
Cerium (Ce)
Praseodymium (Pr)
Neodymium (Nd)
Promethium (Pm)
Samarium (Sm)
Europium (Eu)
Gadolinium (Gd)
Terbium (Tb)
Dysprosium (Dy)
Holmium (Ho)
Erbium (Er)
Thulium (Tm)
Ytterbium (Yb)
And Lutetium (Lu)



In addition,
yttrium (Y) and
scandium (Sc)
are often
grouped with
the lanthanides
and referred to
as REE.



Rare Earth Elements

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Y	Sc													

Light Rare Earth Element Heavy Rare Earth Element

As high technology develops, demand for rare earth metals increases each year. This is particularly evident in the search for clean energy sources and the development of various electronic devices.



In 2021, global production of rare earth elements reached 280,000 tonnes, a significant increase compared to 2018, when 110,000 tonnes fewer were mined.

REE ARE CRUCIAL COMPONENTS OF HIGH-TECH DEVICES, WHICH IS WHY THEY ARE SOMETIMES REFERRED TO AS THE "VITAMINS" OF THE MODERN ECONOMY OR INDUSTRY.

HOUSEHOLDS



Smartphones and tablets

Nd and Pr are used in powerful magnets for speakers, motors, and vibration mechanisms. La and Ce are used in lighting and optical components, such as displays and cameras.



Computers and laptops

Nd is used in fans, speakers, and other components. Ce and La are used in various components, including optical systems and displays. Eu and Tb are used in advanced displays.



Televisions and displays (LCD, OLED)

Tb, Eu and other rare earth elements are used to enhance colour properties and increase the brightness of displays.



LED lights and displays

Tb and Eu are used in colour displays, televisions, and LED lights. Ce is widely used in LED technology to improve brightness and efficiency.



Electronic devices (computer modems, printers)

REEs are found in various electronic components, magnets, optical elements, and some capacitors. Nd and Pr are essential in hard drive magnets and optical devices for reading and writing data.



Solar cells and renewable energy sources

Ce and other rare earth elements are used in certain components of solar cells to enhance performance.

From: <https://www.solarpanel.com/articles/solar-energy-renewable/>



Electric cars

Nd, Dy, and other REE are used in small amounts in the batteries and electric motors that power electric cars, and their use is gradually increasing as electric vehicles become more popular.

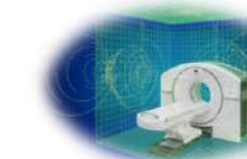
MEDICINE



From: <https://openminds.com/medial-discovery-the-transformative-journey-of-x-ray-technology-in-medicine-and-science/>



From: <https://www.cancer.gov/publications/dictionaries/cancer-terms/def/nuclear-magnetic-resonance-imaging>



From: <https://openminds.com/nuclear-medicine-imaging/> From: <https://www.gophotonics.com/community/lasers-for-medical-applications>

- Portable X-ray instruments
- X-ray tubes
- Magnetic resonance imagery (MRI) contrast agents
- Nuclear medicine imaging
- Cancer treatment applications
- Genetic screening tests
- Medical and dental lasers

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Breast Reconstruction and its Impact on Movement Considerations for Physiotherapy Management

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ABSTRACT

Breast reconstruction after mastectomy is an important part of comprehensive breast cancer care, improving psychosocial well-being and quality of life. However, it may cause movement limitations and functional impairment, especially in the upper limb and, in autologous procedures, at the donor site. Common issues include reduced shoulder mobility, muscle weakness, pain, and altered movement patterns. Implant-based reconstruction is often linked to pectoral tightness, while autologous techniques may cause additional donor site deficits. Individualized physiotherapy plays a key role in improving recovery and function.

METHODS

A narrative literature review was conducted to examine the effects of breast reconstruction on movement and functional outcomes, and the implications for physiotherapy. Articles published between 2000 and 2025 were included. Peer-reviewed studies formed the primary evidence base, providing detailed analyses of surgical techniques, biomechanical consequences, and expected rehabilitation outcomes. Systematic reviews and meta-analyses were used to identify prevailing trends in clinical practice and summarize existing evidence.

CONCLUSION

Breast reconstruction after mastectomy is frequently associated with movement and functional impairments. The extent of dysfunction depends on the reconstruction technique, emphasizing the need for targeted rehabilitation. Evidence supports structured, progressive physiotherapy to improve mobility, strength, and function. Physiotherapists must understand the biomechanical effects of different methods to provide safe, individualized care.

RESULTS

Upper quarter dysfunction is common following all types of breast reconstruction, manifesting as shoulder pain, reduced range of motion, muscle weakness, scapular dyskinesis, and compensatory movement patterns. Chest muscle tightness may persist for up to six months, lymphedema for up to one year, and rotator cuff impairments are frequently reported in the postoperative period.

Implant-based reconstruction is associated with pectoralis major tightness, reduced torque muscle strength, and altered shoulder muscle activation patterns (4). Submuscular implant placement frequently leads to postoperative pain and muscle spasms, promoting protective movement behaviours that further compound shoulder dysfunction and increase the risk of scar tissue formation (3).

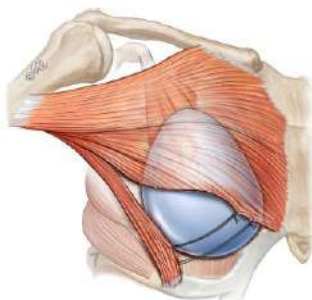


Figure 1. Implant-based reconstruction.

Latissimus dorsi (LAT) flap reconstruction results in significant and potentially long-lasting deficits in shoulder adduction, internal rotation, and extension strength which may persist for up to 3.5 years postoperatively (12). Up to 73% of patients report difficulty with arm-related activities of daily living. Shoulder instability is also commonly reported (7). Residual impairments more prominently affect high-demand and athletic activities than routine functional tasks (1). Functional morbidity tends to adequately improve over time with appropriate rehabilitation.

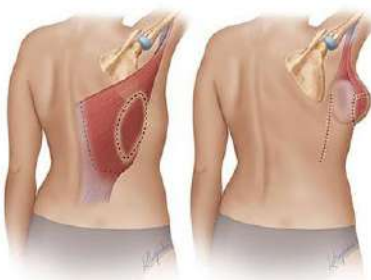


Figure 2. Latissimus dorsi (LAT) flap.

Abdominal-based reconstruction introduces donor site morbidity that affects trunk function. TRAM flap procedures significantly reduce abdominal and back extensor strength and are associated with higher postoperative pain and greater functional impairment compared to other techniques (11). The DIEP flap preserves the rectus abdominis muscle and is associated with lower donor-site morbidity; however, some degree of abdominal weakness may still persist (6). Both techniques may compromise posture and core stability.

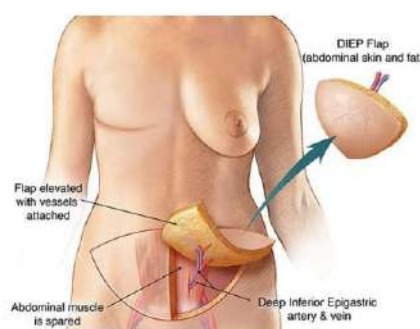


Figure 3. Abdominal-based reconstruction (DIEP flap).

Physiotherapy plays a critical role in recovery across all reconstruction types. In the immediate postoperative period, gentle shoulder extension and adduction exercises are encouraged within pain tolerance, with elevation typically limited to 90° during the first two weeks (8). Between weeks two and four, full range of motion is gradually restored as wound healing progresses. Progressive strengthening is introduced at approximately one month, with return to sport and higher-load activities encouraged after three months. A Cochrane systematic review confirmed that structured postoperative exercise programs are significantly more effective than standard care alone in improving shoulder mobility in both the short and long term (9).

Following implant-based reconstruction, rehabilitation focuses on pectoralis major relaxation and re-training, gradual correction of compensatory movement patterns, and progressive strengthening of the rotator cuff and scapular stabilizers (10). After LAT flap reconstruction, rehabilitation emphasizes strengthening of scapular stabilizers, correction of scapular dyskinesis, activation of latissimus dorsi synergists, and targeted postural exercises to reduce the risk of thoracolumbar scoliosis. For abdominal-based reconstructions, rehabilitation must additionally address trunk and core muscle deficits, preoperative physiotherapy focusing on rectus abdominis strength may also contribute to improved postoperative recovery following DIEP flap procedures (2). Adjunctive therapies such as massage therapy and pulsed electromagnetic field therapy may reduce postoperative pain, inflammation, and anxiety and therefore facilitate earlier participation in active rehabilitation (5).

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Technical Aspects of Breast Compression in Mammography: Patient Comfort and Impact on Image Quality

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ABSTRACT

Breast cancer is one of the most common malignancies among women worldwide, and mammography remains the primary method for early detection. Breast compression is a key technical component that influences image quality, radiation dose, and patient comfort. Adequate compression reduces breast thickness, tissue overlap, and motion, thereby improving image quality. However, it may also cause discomfort or pain, potentially affecting participation in screening programmes. This review summarises the technical aspects of breast compression and its impact on image quality and patient-reported comfort. Findings highlight the importance of achieving a balance between optimal image quality and patient-centred care, emphasizing the critical role of radiographers.

METHODS

A narrative literature review was conducted to examine the technical aspects of breast compression in mammography, with a focus on image quality and patient comfort. Publications from 2004 to 2025 were included. Peer-reviewed studies provided the main evidence base, addressing compression techniques, image quality parameters, radiation dose optimisation, and patient-reported outcomes. Review articles were used to synthesise existing knowledge, while professional guidelines from international and European organisations were included to reflect current clinical practice. Additional sources, such as academic textbooks, supported the anatomical and technical background.

CONCLUSION

Breast compression is a key component of mammography, improving image quality and enabling radiation dose optimisation, but it may also cause patient discomfort. Achieving an optimal balance between technical image quality and patient comfort is essential. Clearer compression guidelines, improved comfort-enhancing technologies, and effective radiographer-patient communication can help reduce discomfort without compromising diagnostic quality. Further research should focus on defining individualised compression parameters and improving patient experience to support screening adherence.

RESULTS

Technical effects of breast compression: Breast compression plays a key role in optimising mammographic image quality. It reduces breast thickness, tissue superimposition, and motion artefacts, resulting in clearer and more diagnostically reliable images (4). Compression improves spatial resolution and contrast, enhances visibility of fine details such as microcalcifications, and contributes to a more uniform image with a higher signal-to-noise ratio (1). Additionally, reduced tissue thickness allows for lower radiation dose and decreased scatter radiation (7).

Compression force and clinical variability: The effectiveness of compression depends on the level of applied force and resulting breast thickness reduction (5). In clinical practice, compression is typically guided by experience and patient feedback rather than strict protocols (7). Due to the lack of standardised guidelines, there is considerable variability in applied compression force. Recommended values generally range between 60 N and 160 N, with an upper limit of approximately 200 N. However, compression is often limited by patient discomfort rather than technical requirements (3).

Patient comfort and influencing factors: Patient discomfort during mammography is a multifactorial issue. Key factors include breast density, age, previous surgical procedures, and individual pain sensitivity. Mechanical factors, particularly compression force and duration, are the main contributors to pain. Psychological factors, such as fear, anxiety, and previous negative experiences, further influence perceived discomfort (6).

Role of communication and technology: Effective communication by radiographers is one of the most important factors in reducing patient discomfort and improving overall experience. Clear explanations and supportive interaction can significantly reduce anxiety and perceived pain (6). Technological advancements, such as curved compression paddles that conform better to the natural shape of the breast and allow a more even distribution of pressure, have shown potential to improve comfort while maintaining image quality (8).

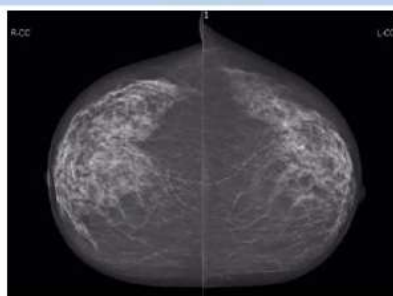


Figure 1. Example of a high-quality mammogram in the craniocaudal (CC) projection.



Figure 2. Example of a high-quality mammogram in the mediolateral oblique (MLO) projection.

Image quality: Breast compression significantly improves mammographic image quality through several mechanisms (4).

- **Reduced geometrical blur:** decreased breast thickness brings structures closer to the detector.
- **Increased spatial resolution:** improved visibility of small structures and microcalcifications.
- **Reduces radiation dose:** thinner tissue requires lower exposure.
- **Decreased motion artefacts:** stabilisation of the breast during imaging.
- **Improved contrast and uniformity:** reduced scatter radiation enhances image clarity and signal-to-noise ratio (4).

These effects enable more accurate detection of subtle lesions and improve overall diagnostic reliability. However, increased compression may also lead to greater patient discomfort, requiring a balanced approach (2).

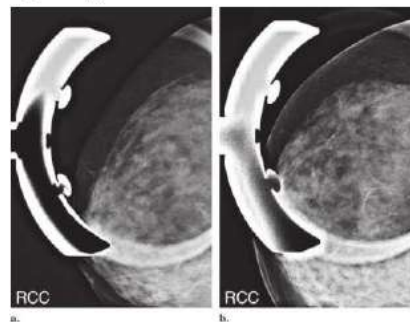


Figure 3. Motion artifact. (a) Right craniocaudal (RCC) mammogram shows blurred microcalcifications and dense breast tissue. (b) On a corrected RCC mammogram, the microcalcifications appear more distinct against a fibroglandular background, and the breast tissue is less dense.

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Effect of heavy metals on extracellular particles of *Chlorellae sorokiniana*

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Outline

Microalgae are of great importance for ecology and industry; however, the mechanisms of ecosystem resiliency and production of economically relevant compounds should be better understood. Here, we focus on adaptive response of microalgae to heavy metals, specifically, manganese (Mn) and copper (Cu). In line with the observation on human neuroblastoma cells in vitro, which expel the metals outside the cell using extracellular particles (EPs) to resist toxicity, we investigated if this could be applied to microalgae.

Methods

Chlorella sorokiniana cultures were treated with 1mM MnCl₂ and CuCl₂ at the early stationary phase (20 days old). During 4 days after treatment, supernatants and pellets obtained by differential centrifugation were observed using Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) with Energy Dispersive Spectroscopy (EDS). We assessed number density and hydrodynamic diameter of EPs by Interferometric Light Microscopy (ILM) (Videodrop, Myriade). Photometry was made on Refeyn 200 MP mass photometer. Single spectrum Raman spectroscopy was made on WiTec Alpha 300 RA spectrometer with 532 nm laser and 50x magnification objective.

Results

SEM revealed numerous microalgae surrounded by amorphous mucilage. In supernatant we observed fractal structures, which were particularly abundant in metal-treated samples. In the pellet of control and Cu-treated samples, SEM and TEM revealed small amount of globular particles. TEM EDS of Cu-treated samples exhibited in the globular particles an increased content of metals with respect to the surroundings. Controls composed of water-added phosphates and copper in the same concentrations as in the culture showed the presence of similarly shaped, albeit larger globular structures. ILM showed the presence of numerous particles (in the range of 10 per mL in the culture and up to 10 times larger in the supernatant), while the detected number density in the culture was under the detection limit. Measurements of the pellets were not feasible due to the presence of the mucilage. Mass photometry and Raman spectroscopy results are given in Figures 3 and 2, respectively.

Conclusions

Extracellular particles observed in microalgae samples may be formed by phosphates contained in the mucilage shed by microalgae. Our results support the assumption of accumulation of copper by EPs composed by extracellular material shed by microalgae.

Table 1. Interferometric light microscopy measurement of number density and hydrodynamic diameter of nanoparticles (between 80 and 500 nm).

Time	Sample	Dil.	S5000g AV.C. 10 ³ /mL	S5000g corr AV.C. 10 ³ /mL	S5000g Dh (nm)	Dil.	Culture AV.C. 10 ³ /mL	Culture corr AV.C. 10 ³ /mL	Culture Dh (nm)
15'	Algae	1	1.04	1.04±0.07	187±14	10	0.10	1.00±0.20	233±33
	Algae+Cu	10	2.85	28.50±0.170	204±4	10	2.74	27.37±1.10	225±5
	Algae+Mn	10	2.71	2.87±0.31	205±12	10	0.41	4.10±0.40	211±16
60'	Algae	1	1.10	1.10±0.70	190±7	10	0.09	0.87±0.00	184±29
	Algae+Cu	10	2.59	25.90±0.80	213±8	10	2.53	25.33±2.80	230±4
	Algae+Mn	10	2.56	25.60±0.10	202±3	10	0.39	3.90±0.90	232±7
24h	Algae	10	0.11	0.97±0.30	206±48	10	0.57	0.57±0.10	260±40
	Algae+Cu	1	3.24	3.34±0.15	193±7	10	2.79	27.89±1.50	234±23
	Algae+Mn	20	3.79	75.87±3.60	167±4	10	6.29	62.90±4.30	291±22
48h	Algae	30	2.78	83.4±0.90	179±7	20	0.35	7.00±0.30	195±10
	Algae+Cu	1	2.34	2.34±0.15	187±20	10	0.17	1.70±0.20	209±24
	Algae+Mn	1	10.50	10.50±0.06	207±7	10	2.64	26.37±1.30	202±64
		2.5	5.44	13.59±1.02	208±4				
		5	2.53	12.67±1.25	205±5				
		7.5	1.64	12.30±1.05	201±4				
		10	0.98	9.83±0.60	211±4				
		15	1.02	15.35±0.90	207±7				
	Algae+Mn	1	7.14	7.14±0.36	244±3	10	0.93	9.33±0.60	282±15
		2.5	1.51	3.78±0.14	208±7				
		5	1.77	8.83±0.70	205±9				
		7.5	1.77	13.34±1.28	167±24				
		10	1.12	11.17±0.20	226±3				
		15	0.53	7.90±0.30	219±2				
72h	Algae	1	1.46	1.46±0.05	225±4	10	0.20	2.00±0.20	278±39
	Algae+Cu	10	3.29	32.93±1.12	225±24	10	8.29	82.93±0.90	192±9
	Algae+Mn	30	2.71	81.20±2.70	203±6	20	4.26	85.2±0.50	204±110
		30				30	3.08	92.50±1.30	198±3

Dil.: dilution, corr: corrected for dilution, S: supernatant, AV.C.: average number density, g: gravity acceleration of Earth. Time: time after treatment with metals. Results are given +/- standard deviations.

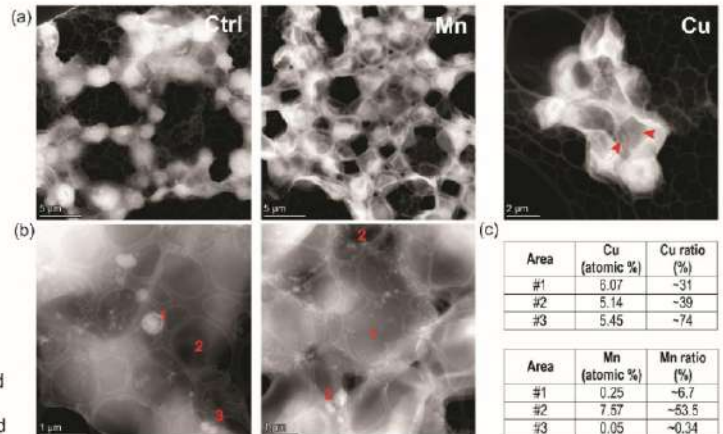


Figure 1. (a): Representative TEM micrographs of *Chlorellae sorokiniana* cells under control conditions and after treatment with 1 mM MnCl₂ or 1 mM CuCl₂ for 72h, recorded using the HAADF-STEM imaging mode, (b): EDS analysis regions are marked with numbers. (c): The table summarizes the atomic fraction (%) of Mn or Cu within the overall elemental composition and the calculated Mn or Cu ratio relative to the biologically relevant intracellular metals (Na, K, Mg, Ca).

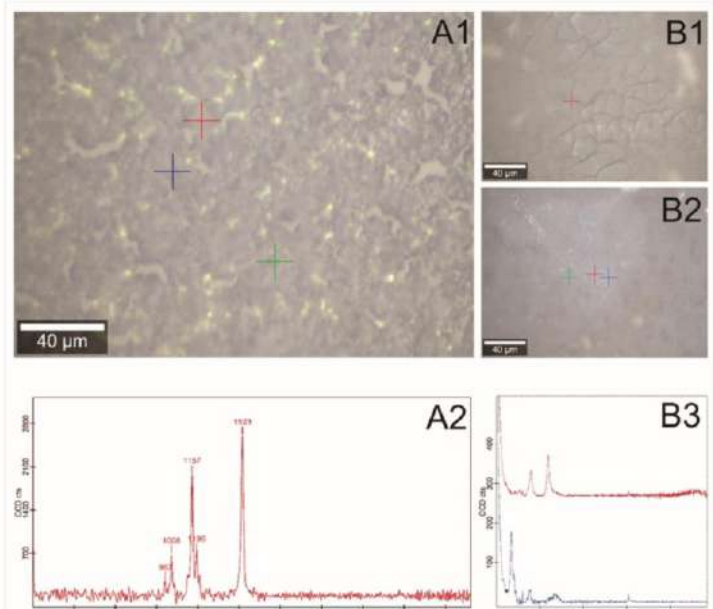


Figure 2. A1: Raman micrograph of a representative sample of microalgae culture and A2: the corresponding spectrum pertaining to the red cross in A1. B1 and B2: Raman micrographs of microalgae samples treated with metals. Samples had carotene signal. B3: Microalgae - blind measurements.

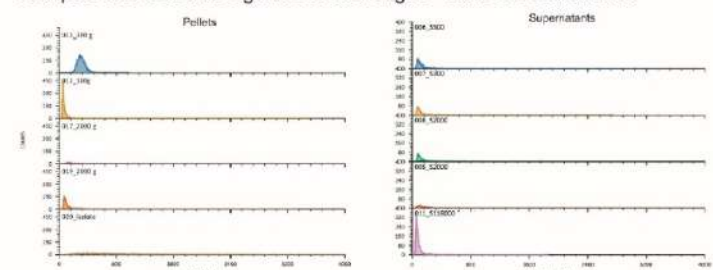


Figure 3. Mass photometry along the differential centrifugation. At lower forces, pellets were richer than supernatants. In particular at the last step, the supernatant was richer than the isolate. Most of the molecules were in the range (100-200)kDa. There were also larger particles present.



Optimization of Human Plasma Preservation Method as a Standard for Biological Analysis

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INTRODUCTION

Currently, most research in the field of biochemical robots is centered on plasma control and calibration. This focus is natural, since plasma-based control and calibration enable the robot to carry out its intended functions efficiently. Without plasma control, for example, robots would be unable to communicate their functions. Advances in techniques for manipulating, generating, and monitoring plasma have greatly improved the plasma-control process, and these improved techniques are essential for ensuring a stable and effective plasma environment. Calibration is likewise crucial to make sure biochemical robots behave accurately and predictably. Because robots, like all devices, are prone to errors, calibration becomes necessary; if such errors accumulate, they can undermine the robot's reliability. In the event of a control-system failure, robots may become dangerous, as the control system could direct them into potentially hazardous and unexpected movements.¹ Control systems for biochemical robots usually require three kinds of calibration: actuator calibration, sensor calibration, and motion calibration. Customizable robots allow designers and users to rely on generic hardware that can easily be configured to support a wide range of movements and interactions. The behaviors displayed by a biochemical robot using plasma control and calibration are highly significant in any given design task, because they reveal the robot's true attributes. Plasma control, together with calibration, offers a unique way to observe the robot in terms of control and motion. While plasma calibration is under way, the robot's calibration window in the software is updated in real time, allowing the robot's processor to adjust to the plasma environment. Integrating plasma control and calibration into biochemical robots has opened new avenues for exploring robot movement and behavior.²

These methods also hold promise for designing more autonomous robots that can adapt to changes in both their surroundings and their own physical conditions. AI-based plasma calibration supports the plasma-control software by allowing users to define the palette of a given species in the plasma recipe editor—an especially important feature when multiple gas types are used. To ensure correct final results, please provide the machine-translated file and, using AssistEdit, help us improve the translation.³

MATERIALS AND METHODS

Blood Collection Techniques

Pathogenic and Normal Plasma Populations

Plasma Separation Equipment and Techniques

Spectrophotometer: MINDRAY BA-88A

Biochemistry Analyzer: MINDRAY BS 240

Diagnostic Reagents with Standards

Sample Preservation: Freezers at -30 °C and between -5 to -8 °C

Discussion of Results

The conservation of human plasma is essential to ensure the reliability of biochemical analyses. However, current preservation methods present limitations, particularly when it comes to the long-term storage of biomarkers. This study aims to assess the stability of key biomarkers — glucose, urea, creatinine, cholesterol, and triglycerides — over a period of 90 days using three different storage methods: freezing at -30 °C, storage at -5 °C/-8 °C without chemical stabilizers, and storage at -5 °C/-8 °C with the addition of stabilizers. The goal is to evaluate the effectiveness of each method to potentially use the samples as reliable reference standards.

Plasma samples were subjected to these three storage conditions. To ensure precise and reproducible measurements, analyses were carried out using a Mindray biochemistry analyzer. The results showed that freezing at -30 °C allowed for optimal preservation with minimal variability across the biomarkers. In contrast, rapid degradation was observed in samples stored at -5 °C/-8 °C without stabilizers. Notably, the use of chemical stabilizers at the same storage temperature significantly improved biomarker stability, producing results comparable to those obtained with freezing.

In conclusion, freezing at -30 °C remains the most reliable method for long-term storage of plasma biomarkers. However, the incorporation of chemical stabilizers presents a viable alternative, particularly in settings where advanced refrigeration infrastructure is limited. A combined approach utilizing both freezing and chemical stabilization could help optimize the quality of plasma samples for biomedical applications.

CONCLUSION

The key findings of this study demonstrate that storing human plasma at -30 °C is the most effective method for preserving critical biomarkers such as glucose, urea, creatinine, cholesterol, and triglycerides. This temperature ensures excellent analyte stability, which is essential for maintaining the reliability of subsequent biochemical analyses.

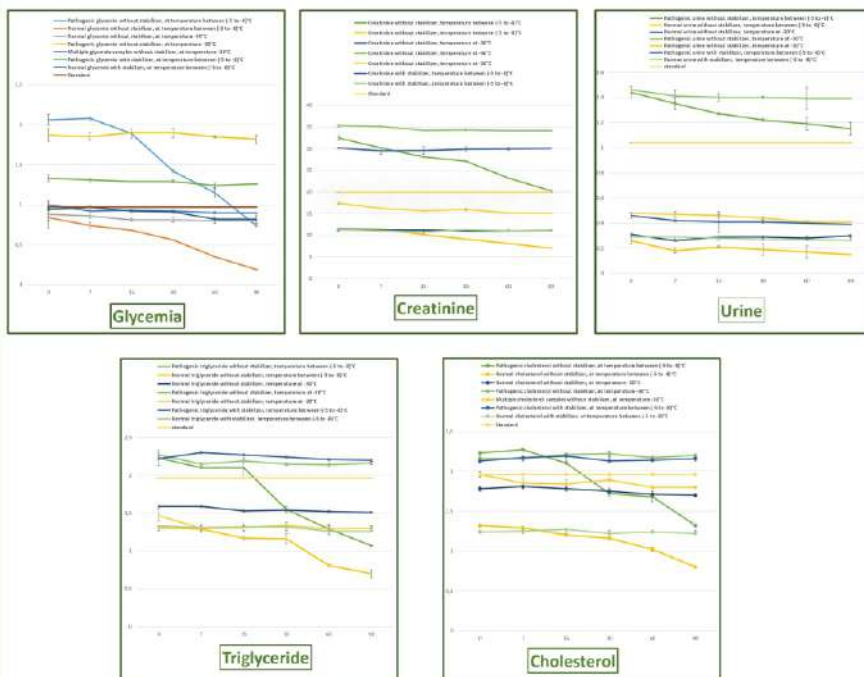
Additionally, storing plasma at -5 °C to -8 °C with added chemical stabilizers also proved to be effective, showing significantly better biomarker preservation than storage without stabilizers. These findings highlight the importance of plasma stabilization protocols, especially in settings where deep freezing infrastructure is limited.

These conclusions carry important implications for medical practice and clinical diagnostics, particularly in the monitoring of patients with metabolic disorders. Healthcare professionals are thus encouraged to adopt appropriate storage techniques to ensure the accuracy and reliability of laboratory results.

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RESULTS



Artefacts on mammograms: recognition, causes and prevention.

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ABSTRACT

Digital mammography represents the foundation of modern screening and diagnostic strategies for breast cancer detection, as it enables high resolution imaging, precise visualization of tissue structures, and early identification of pathological changes.

Mammography is an imaging method that uses low-dose x-rays to create detailed pictures of the breast. Mammograms are performed in at least two standard views, the craniocaudal view (CC) and the mediolateral oblique (MLO).

The recognition and prevention of artefacts in mammography is a crucial role in ensuring accurate detection of breast pathology. Artefacts can be divided into four main groups: patient related, detector based, equipment related and post-acquisition related.

METHODS

A systematic analysis of scientific literature was conducted for the review, published between 1995 and 2025 was conducted, with emphasis on studies addressing artefacts in digital mammography, contrast-enhanced mammography, and methods for their detection, classification, and clinical management.

Included were articles describing the technical mechanisms underlying artefact formation, their impact on diagnostic image quality, and contemporary approaches to artefact reduction, including artificial intelligence algorithms and transfer learning techniques and what we can do to prevent them.

CONCLUSION

Artifacts in mammography represent a significant challenge in breast imaging, as they can obscure pathology or produce false results, potentially leading to diagnostic errors. Artifacts can arise from patient-related factors, equipment issues, and technique-dependent processes, with each contributing in its own way to reduced image quality and diagnostic reliability.

Effective recognition of artifacts requires a combination of clinical experience, technical knowledge, and attention to detail from both radiographers and radiologists. Overall, maintaining high diagnostic accuracy, reducing unnecessary repeat examinations, and improving breast cancer detection outcomes critically depend on heightened awareness, preventive strategies, and careful artifact recognition.

RESULTS

Screening mammograms are performed in at least two standard views, which include the craniocaudal view (CC) and the mediolateral oblique (MLO).

By comparing these two different viewpoints, structures that are superimposed upon one another in one view may be separated in the other.



Figure 1: Standard views in mammography. On the left two pictures (a and b) is represented craniocaudal view (CC), while the right two pictures show (c and d) mediolateral oblique view (MLO) (Radiological Anatomy, 2023).

Artefacts on mammograms: artifacts reduce quality of mammograms and can create pseudolesions or mask abnormalities leading to misinterpretation. Radiographers are the first to encounter patients and perform the examination, so it is important that they know how to recognize artifacts in images, understand why they occur, and know how to reduce or prevent them if possible. Artifacts can be patient related (patient motion, superimposition of objects or other parts of the body over the breast), detector based (dead pixels, dead or unread lines, ghosting), equipment related (other components on the gantry) or post acquisition related (failure to properly reconstruct the image at the review station or inability of the processing algorithm to compensate for differences in exposure across the detector).

Artefact recognition: Different artefacts show in different ways, but they do have one thing in common and that is, that they remain stable with repeated imaging.

Causes of artefacts:

Artefacts on mammogram can be caused by various factors. Patient-related artefacts arise from physical factors external to the imaging system.

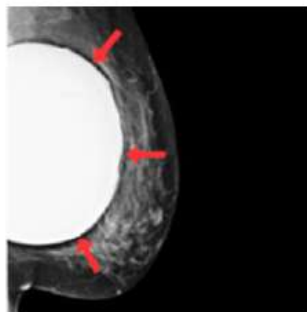


Figure 2: Breast implant, where can be seen that we have an obscured view of surrounding tissue. Because of the higher attenuation of x-ray photons in the breast implant, the overall quality of the mammogram is not as good (Singla et al. 2025).

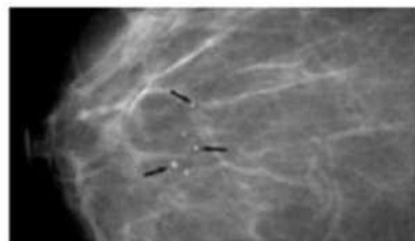


Figure 3: Artefacts caused by dust and dirt that mimic calcifications (Singla et al, 2025).

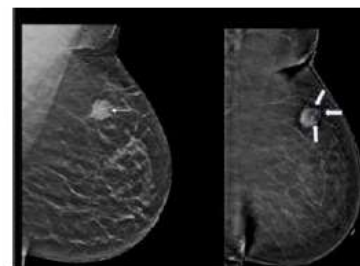


Figure 4: Rim artefact. Left side shows contrast enhanced mammography, mediolateral view (MLO), low energy image, showing high density mass with spiculated margin (white arrow). Right side, recombined image, the mass shows heterogeneous post contrast enhancement with surrounding rim artefact (white block arrows), seen as black line around the mass (Singla et al. 2025).

Prevention on artefacts

Artefacts are not that hard to prevent if we take the correct protocols. Patient-related artefacts are prevented by removing clothing and hair, careful positioning and good compression, as it disables motion. Patients should not use antiperspirant on exam day and should clean axilla prior to imaging to prevent antiperspirant artefacts. When imaging patients with breast implants Eklund's technique ought to be used and magnetic resonance imaging (MRI) is preferred.

Equipment-related artefacts that occur due to x-ray tube malfunction may be prevented with daily check-ups and weekly gain calibrations, since the issue can be spotted during the quality control tests. Artefact caused by dirt or dust can be avoided with visual inspection of detector/film surface and regular cleaning. Dual-energy artefact, which belongs to the technique-dependant artefacts can be averted with the proper timing between low-energy and high-energy image captures and correct exposition parameters. Rim artefact in CEM is trickier to prevent as it needs update software and good post-processing.

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Lymphoedema after Breast Cancer Surgery: Anatomical Background and Physiotherapy Interventions

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ABSTRACT

Breast cancer-related lymphoedema (BCRL) is a common long-term complication following breast cancer treatment, resulting from impaired lymphatic transport due to surgical and radiotherapeutic damage. It leads to accumulation of protein-rich interstitial fluid, causing swelling, functional impairment, and reduced quality of life.

Physiotherapy represents the cornerstone of conservative management, particularly through complex decongestive therapy (CDT), which integrates compression therapy, manual lymphatic drainage, therapeutic exercise, skin care, and patient

METHODS

A narrative literature review was conducted to examine the anatomical background, pathophysiology, and physiotherapy management of BCRL. Scientific articles published from 2001 onwards were identified using PubMed and ResearchGate databases.

Peer-reviewed studies, systematic reviews, and meta-analyses were included to provide an overview of current evidence and clinical practice trends (1).

CONCLUSION

BCRL is a chronic and progressive condition associated with disruption of lymphatic pathways following breast cancer treatment.

Physiotherapy, particularly CDT, represents the cornerstone of management. Early detection, individualized treatment, and interdisciplinary care are essential for optimal long-term outcomes.

RESULTS

Pathophysiology

Breast cancer-related lymphoedema (BCRL) develops as a consequence of impaired lymphatic transport capacity following surgical and radiotherapy-induced damage to lymphatic vessels and nodes (1,2). Disruption of lymphatic pathways leads to the accumulation of protein-rich interstitial fluid, which initiates a chronic inflammatory response within the affected tissues (1,2).

This inflammatory process promotes infiltration of immune cells and the release of pro-inflammatory mediators, resulting in progressive fibrosis and adipose tissue deposition (2,3). Over time, these structural changes reduce lymphatic vessel compliance and further impair lymph transport, contributing to the chronic and progressive nature of the condition (1,2,3).

Importantly, BCRL is no longer considered a purely mechanical disorder but rather a complex chronic inflammatory disease, where lymphatic injury triggers long-term pathological changes that may become irreversible if not managed early (1,2).

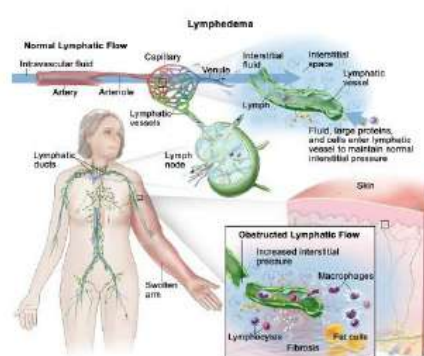


Figure 1. Figure 1: Pathophysiology of lymphoedema: comparison of normal and obstructed lymphatic flow. Adapted from the National Cancer Institute (NCI) Lymphedema (PDQ®)—Health Professional Version. Illustration © Terese Winslow, U.S. Government.

Risk Factors

The development of BCRL is multifactorial and influenced by both treatment-related and patient-related factors (4). The most significant risk factor is axillary lymph node dissection, which causes extensive disruption of lymphatic drainage pathways (4). Although sentinel lymph node biopsy is less invasive, it still carries a measurable risk, particularly when combined with adjuvant therapies such as radiotherapy (1,4).

Radiotherapy further contributes to lymphatic damage by inducing fibrosis of soft tissues and reducing lymphatic vessel function (1,4). Patient-related factors such as high body mass index and postoperative weight gain have been consistently identified as independent predictors of

In addition, postoperative complications, including infection and seroma formation, may further increase the risk by exacerbating inflammatory processes and delaying lymphatic recovery (1,4). These findings highlight the importance of early risk identification and long-term monitoring in breast cancer survivors.

Clinical Presentation

Clinical presentation is variable and often develops gradually. Early symptoms include heaviness, tightness, and discomfort in the affected limb, while later stages are characterized by visible swelling and functional limitations (6).

Patients frequently experience reduced range of motion, decreased strength, and difficulties in daily activities, which significantly affect quality of life (6).

Physiotherapy Management

Physiotherapy represents a central component of conservative BCRL management, aiming to reduce oedema, improve upper limb function, and support long-term self-management (7). A multimodal and individualized approach is recommended to address the complex pathophysiology of the condition (7).

Complex decongestive therapy (CDT) is considered the gold standard treatment and consists of manual lymphatic drainage, compression therapy, therapeutic exercise, skin care, and patient education (7,8). Evidence shows that CDT leads to clinically meaningful reductions in limb volume and improvements in functional outcomes when applied consistently and over a sufficient duration (7,8).

Manual lymphatic drainage is used to stimulate lymph flow and redirect fluid toward functioning lymphatic pathways, while compression therapy plays a key role in maintaining volume reduction and preventing fluid reaccumulation (7). Skin care is essential for preventing infections, which may worsen lymphoedema and further impair lymphatic function (1,7).



Figure 2. Figure 2: Compression bandaging of the upper

Therapeutic exercise is an important active component of physiotherapy. Current evidence demonstrates that progressive resistance training does not exacerbate lymphoedema and is safe for breast cancer survivors (8). On the contrary, it contributes to improvements in muscle strength, functional capacity, and overall quality of life when properly prescribed and supervised (7,8). In addition to CDT, several adjunct interventions have been investigated. Kinesiotaping may improve functional outcomes and perceived quality of life, although its effect on limb volume reduction remains inconsistent (9).

Hydrotherapy has been shown to provide short-term benefits in pain reduction and range of motion, particularly due to the hydrostatic pressure of water (8,9).

Photobiomodulation therapy has also demonstrated potential benefits; however, current evidence remains limited and heterogeneous (9). Patient education represents a crucial component of long-term management. It focuses on self-monitoring, appropriate use of compression garments, maintenance of physical activity, and early recognition of symptoms (7). Active patient participation is essential for maintaining treatment outcomes and preventing disease progression (7,8).

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ISOLATION AND PROFILING OF EXTRACELLULAR VESICLE-ASSOCIATED RNA FROM *VERTICILLIUM NONALFALFAE*

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BACKGROUND

Verticillium nonalfalfae is a soil-borne phytopathogen that causes Verticillium wilt, a vascular disease affecting numerous economically important crops. Successful fungal infection requires a complex molecular interaction between the fungus and its host. Therefore, understanding the mechanisms that underlie the host-pathogen interaction is essential to develop new combat strategies. Extracellular vesicles (EVs) have emerged as potential mediators of cross-kingdom communication, as they enable the transport of biologically active molecular cargo, including RNA. Recent studies suggest that fungal pathogens may exploit RNA delivery pathways, such as vesicle-mediated RNA transfer to promote infection.

GROWTH MEDIA

- Czapek-Dox medium (CDA)
- or
- Xylem simulating medium (XSM)

ISOLATION OF EXTRACELLULAR VESICLES (EVs)

- Differential ultracentrifugation

METHODS

- Characterization
- Interferometric light microscopy (Videodrop, Myriade)

PRELIMINARY SEQUENCING OF EV-ASSOCIATED RNA

- IonChef™

RNA ISOLATION

- Monarch Total RNA Miniprep kit
- mirVana miRNA Isolation kit

RESULTS

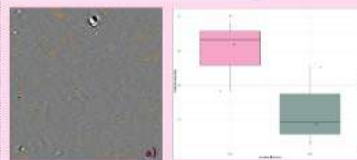


Figure 1: a) Visualization of isolated particles by interferometric light microscopy (Videodrop, Myriade). b) Distribution of particle sizes of vesicles isolated from CDA or XSM medium. A one-way ANOVA indicated no statistically significant difference in particle size between the two media, $F(1, 4) = 3.63$, $p = 0.129$.

	Total sequences	Mapped sequences (%)
small CDA 1	1.20 M	51.66
small CDA 2	1.42 M	68.30
small XSM 1	6.07 M	82.29
small XSM 2	5.20 M	79.05
total CDA 1	2.35 M	81.52
total CDA 2	2.32 M	83.92
total XSM 1	1.30 M	81.85
total XSM 2	1.89 M	86.91

Table 1: Overview of the sequencing output and mapping efficiency to reference fungal genome for each sample. The table shows the total number of raw reads and the percentage of reads that successfully mapped to the reference genome. The values provide an assessment of sequencing depth and data quality prior to downstream analysis.

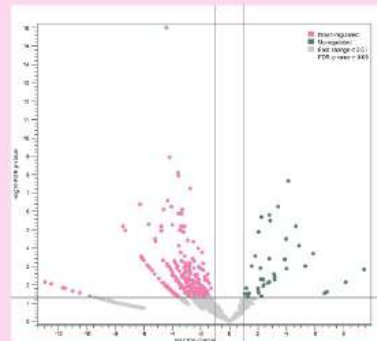


Figure 2: Differential expression analysis of transcripts from total RNA detected in fungal extracellular vesicles. Transcripts significantly downregulated in EVs isolated from the XSM medium compared to the CDA medium are shown in pink ($\text{Log}_2\text{fold change} \leq -2$, $\text{FDR-ps}0.05$), while the significantly upregulated transcripts are shown in green ($\text{Log}_2\text{fold change} \geq 2$, $\text{FDR-ps}0.05$).

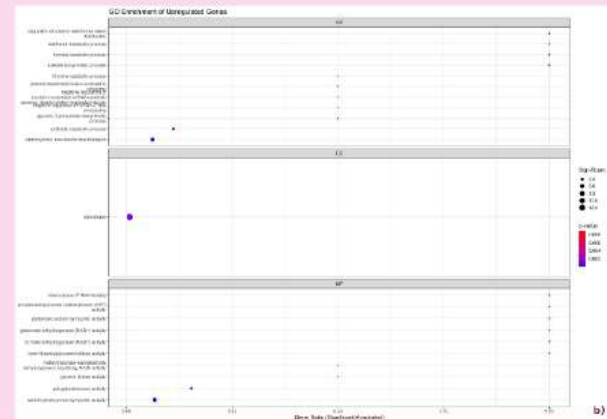
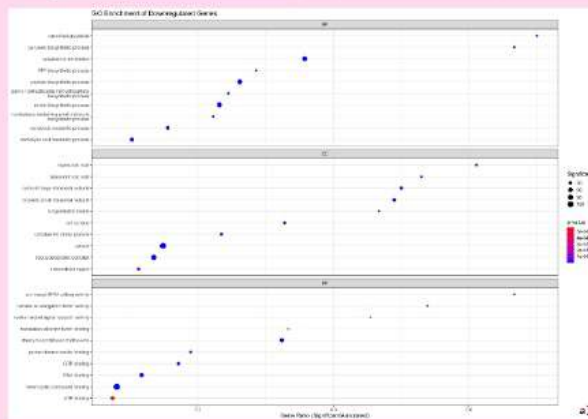


Figure 3: Gene Ontology (GO) enrichment analysis of transcripts detected in extracellular vesicles from preliminary total RNA sequencing data. The graphs highlight the significantly overrepresented biological processes, cellular components and molecular functions associated with: a) transcripts downregulated in EVs isolated from the XSM medium compared to EVs isolated from the CDA medium. b) transcripts upregulated in EVs isolated from the XSM medium compared to EVs isolated from the CDA medium.

CONCLUSION

The particles isolated from both media exhibited sizes within the 100–300 nm range, consistent with the characteristics dimensions of fungal extracellular vesicles. The results demonstrate that the composition of fungal extracellular vesicles is influenced by the growth medium, with the differential expression analysis revealing distinct sets of transcripts up- and downregulated in EVs from XSM compared to CDA. These findings suggest that EV cargo responds to environmental cues and may play a role in host interaction. Future work will expand these analyses by comparing EV-associated RNA with intracellular fungal RNA to assess selective RNA packaging, alongside comparative profiling of *V. nonalfalfae* strains with contrasting virulence to identify pathogenicity-related RNA signatures.

FUNDING

This research was supported by the Slovenian Research and Innovation Agency (ARIS), grant number P4-0077 and ARIS grant to young researcher Miona Kovachevikj.

EXPLORING ENVIRONMENTAL HEALTH AND CONTAMINANTS USING COMMON DUCKWEED (LEMNA MINOR) AS A MODEL SYSTEM

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SOCRATIC
LECTURES



Common, also known as lesser duckweed (*Lemna minor*) is an aquatic plant from the family Lemnaceae, found on the surface of freshwater ponds and lakes worldwide. It is characterized by rapid growth and high biomass accumulation, making it an important food source for aquatic organisms such as fish and invertebrates.

Lemna minor is a model organism widely used in ecology and plant biotechnology research. In addition, it plays an important role in wastewater treatment, as it effectively accumulates heavy metals and other pollutants. Due to its high nutrient content, it is also being researched as a potential source of protein for both humans and animals.

MORPHOLOGICAL CHARACTERISTICS

Common duckweed grows in small floating fronds. Fronds are elliptical or oval, measuring 2–6 mm in length. Each plant has 1–8 leaf-like structures connected with each other by a thin, thread-like structure. The roots of *Lemna minor* are white and 0.5–15 cm in length. This simple structure contributes to its fast growth and adaptability.

ENVIRONMENTAL FACTORS AFFECTING ITS GROWTH

Temperature plays a crucial role, with optimal growth occurring at around 26 °C, while higher temperatures can inhibit development.

Light intensity directly affects the rate of photosynthesis, and increased light availability generally promotes faster growth and biomass accumulation.

Nutrient availability, particularly the ratio of nitrogen to phosphorus, is essential for proper growth and metabolic balance, as *Lemna minor* depends on external nitrogen sources for development.

Changes in pH, salinity, and osmotic conditions can act as stress factors, influencing physiological processes and limiting growth under unfavorable conditions.

Lemna minor reproduces mainly asexually by budding, allowing extremely rapid population growth. Its biomass can double every 48–72 hours and each plant can produce up to 18 daughter plants. Under unfavorable conditions, common duckweed forms turions, specialized, dormant, starch-rich vegetative buds or shoots with the capability to grow into a complete plant, which sink and survive until conditions improve.

APPLICATIONS

Lemna minor grows rapidly and is widely used in research, water purification, and sustainable food production, with potential as a future protein source. It supports ecosystems by producing oxygen, providing habitat, and absorbing nutrients and pollutants to improve water quality. It also accumulates heavy metals, making it valuable for phytoremediation and as a model organism for monitoring environmental stress and water quality.

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- Pictures: (a) <https://en.wikipedia.org/wiki/Lemna> (b) <https://www.lemna.farm/technology> (c) https://goflora.net/families/lemnaceae/lemna/lemna_minor/lemna_minor_3_en.html (d) <https://eu.poughkeepsiejournal.com/story/tech/science/environment/2015/09/24/algal-blooms-duckweed-fall/72410944/>

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Empowering
Communities



IMPLEMENTATION OF ESP32 IN THE SECONDARY SCHOOL CURRICULUM

ESP32



WHY ESP32?

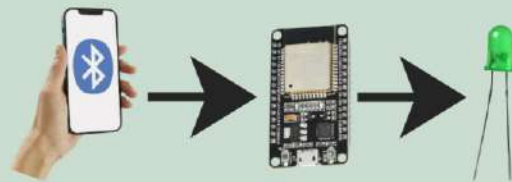
Wi-Fi / Bluetooth 

Arduino IDE 

Dual Core CPU 

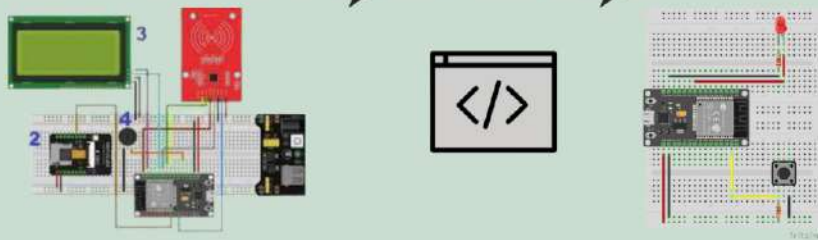
PROJECT EXAMPLES

LED On/Off Control via Bluetooth from Smartphone

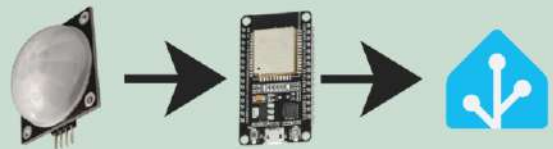


METHODOLOGY AND COURSE OF WORK

Introduction to hardware → Programming → Project work



Motion Sensor Reporting to Home Assistant



RESULTS AND FINDINGS

- Higher student engagement
- Improved technical skills
- Challenges encountered: battery driven designs require more planning

CONCLUSION

The introduction of the ESP32 into the secondary school curriculum has shown that it is possible to successfully connect theoretical knowledge of electronics with practical IoT projects already at the high school level.

UNLOCKING THE SECRETS OF POLYPHENOLS AND ANTIOXIDANTS FOR EVERYDAY HEALTH

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ABSTRACT

Polyphenols are plant secondary metabolites with strong antioxidant properties that neutralize free radicals and reduce oxidative stress associated with aging and chronic diseases. Classified as flavonoids, phenolic acids, stilbenes, and lignans, they are widely found in fruits, vegetables, grains, and beverages. Their properties include anti-inflammatory, antimicrobial, cardioprotective, neuroprotective, and anticancer effects. They also show potential against multidrug-resistant pathogens and in managing degenerative and neurological disorders, partly through the inhibition of enzymes and the regulation of cellular oxidative and inflammatory pathways.

WHAT ARE POLYPHENOLS AND ANTIOXIDANTS?

Antioxidants are any molecules that can slow down or prevent damage to body's cells caused by highly reactive, unstable molecules called free radicals or reactive oxygen species (ROS). Antioxidants work by stabilizing these free radicals, stopping them from negatively impacting cells' proteins, DNA or membranes. Sources of free radicals can among others be normal metabolism, inflammation, exercise, pollution, UV radiation, smoking and poor diet¹.

When free radicals overwhelm body's antioxidant defences, it leads to a state called oxidative stress. Long-term oxidative stress is linked to cell damage that contributes to aging and the development of many chronic diseases, including heart disease, certain cancers, type 2 diabetes, and neurodegenerative diseases like Alzheimer's^{1,2}.

Polyphenols have gained significant interest among researchers due to their potential in chemoprevention and prevention of other various chronic diseases due to their antioxidant properties. Their intakes from fruit, vegetables, seeds, and nuts have been associated with lower risks of chronic and age-related degenerative diseases^{1,3}.

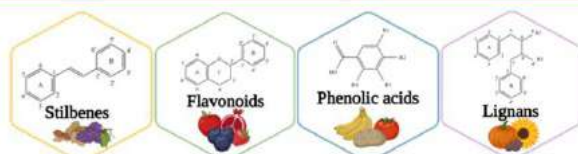


Figure 1: Types of polyphenols⁷.

CLASSIFICATION OF POLYPHENOLS

There are approximately 10,000 natural analogues. These aromatic compounds are often found as bright colored (yellow to red) pigments in the microbes and plants. They are divided based on the number of aromatic (phenolic) rings they contain and the structural elements that connect these rings¹.

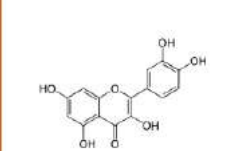


Figure 2: Structure of quercetin.

Flavonoids

They are divided into flavonols, flavones, isoflavones, flavanones, flavanols, and anthocyanins². They are the most studied group of polyphenols, particularly their enzyme-blocking abilities, inhibition of enzymes, use for countering antibiotic resistance and the possibility of using them to detoxify cancerogenic cells. Because of their wide range of health benefits, quercetin and naringenin are two of the more researched flavonoids⁴.

Phenolic acids

Phenolic acids are further divided into hydroxybenzoic acids (HBA) represented by gallic acid, protocatechuic acid, etc., and hydroxycinnamic acids (HCAs) represented by chlorogenic acid, ferulic acid, caffeic acid, etc.³.

HCAs are more likely to find in plants than HBA. HBA is also more common in small quantities. It is often highlighted in literature that absorption of both groups is very good⁴.

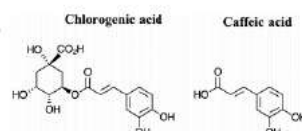


Figure 3: Structure of chlorogenic acid and caffeic acid.

Stilbenes

They are usually produced in plant during biotic and abiotic stress like extreme heat, oxidation, or microbial attacks³. Resveratrol, which is most studied of all stilbenes and is found in grapes abundantly, can stimulate Silent information regulator 2 (Sir2). It helps with calorie restriction and consequently with obesity epidemic⁴.

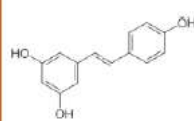


Figure 4: Structure of resveratrol.

Lignans

They are product of polymerization of two phenylpropanoid derivatives (namely C₆-C₃ monomers)³. Differences in structure come from varying substitutions on the aromatic rings and because of different oxidation patterns. They are most commonly found in flaxseeds and sesame seeds, but their bioavailability heavily depends on gut microbiota composition⁴.

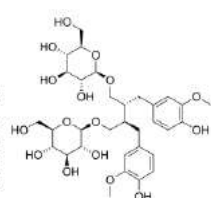


Figure 5: Structure of secoisolariciresinol diglucoside.

FUNCTION OF DIETARY POLYPHENOLS

Polyphenols have a wide range of biological activities, including anti-inflammatory, anti-infective, antiproliferative, antimicrobial, and antioxidant effects, due to their chemical structure, which includes one or more hydroxyl groups attached to a benzene ring⁵. This structural feature allows them to scavenge and neutralize free radicals and ROS, thereby protecting cells from oxidative damage, including the degradation of DNA^{1,3}. As antimicrobial resistance continues to rise, polyphenols have attracted attention as potential agents for treating infections involving multidrug-resistant bacterial strains. In addition, plant-based polyphenol extracts are considered important contributors to the advancement of innovative antimicrobial treatment strategies⁵. Polyphenols have demonstrated activity against various chronic degenerative and neurological diseases⁶. Regular consumption of phenolic compounds (PCs), has been linked to a reduced risk of both cardiovascular and neurological disorders^{1,6}. Flavonoids exhibit strong cardioprotective effects by inhibiting LDL oxidation and platelet aggregation, thereby helping to prevent atherosclerosis and thrombosis. Research indicates that a daily dietary intake of flavonoids may lower the risk of coronary heart disease (CHD)-related morbidity and mortality⁶. In oncology, polyphenols are utilized for both treatment and preventive purposes due to their ability to stimulate ROS production and trigger apoptotic pathways that result in cancer cell death^{1,4}. Polyphenols exhibit the capacity to regulate inflammation-related signalling pathways implicated in arthropathies such as gout, osteoarthritis, and rheumatoid arthritis (RA)¹. They also act as enzyme inhibitors and are utilized in managing dementia by targeting acetylcholinesterase activity in the brain⁴.

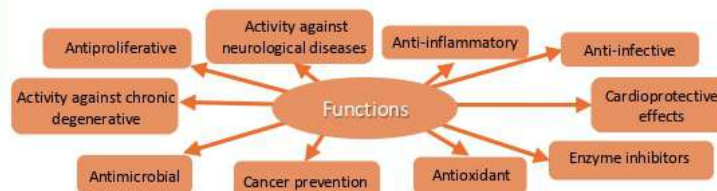


Figure 6: Functions of dietary polyphenols.

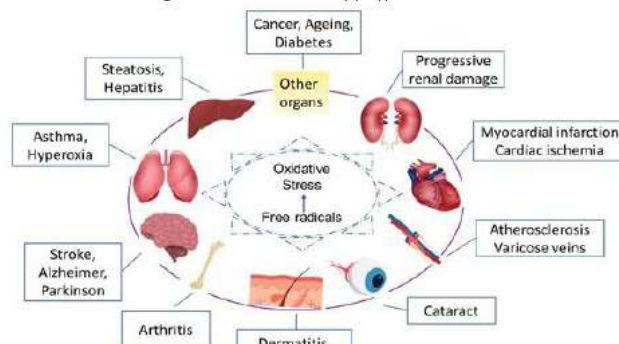


Figure 7: Most frequent pathologies related to oxidative stress⁸.

CONCLUSION

Polyphenols are a large group of plant derived compounds. They are of great interest to researchers due to their antioxidant, antimicrobial, anti inflammatory, cardioprotective, neuroprotective, and anticancer properties. Regular dietary intake through plant based foods may support disease prevention and overall health. Ongoing research highlights their therapeutic potential, particularly in addressing drug resistant infections and degenerative disorders, making polyphenols valuable for future medical and nutritional applications.

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