

Grand Final
International Natural Sciences Tournament 2024
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Grand Final Problems

International Natural Sciences Tournament 2024

1st block (6 problems)



Photo reference: Pulpulak "Seven Springs" / RARE Water Armenia

1. Perfect Pulpulak

Armenia is known for its pulpulaks (Armenian: պղպղակ), public drinking water fountains that make clean drinking water available for everyone everywhere [1]. Not all countries can brag about such availability and tap water* quality also often remains a point of concern [2]. Apart from drinking, tap water is used for various purposes, requirements for which can be different.

Suggest:

- Range of electrolyte/chemical composition which can make tap water suitable for various purposes (consider drinking, washing clothes, showering, watering plants among others);
- Mechanism of improving quality of poor tap water in a known region of your home country to drinking standards [3];
- Household device(s) that can improve tap water quality making it suitable for each of these purposes (drinking, washing clothes, showering, watering plants).

* By "tap water" we mean any water used for drinking and domestic purposes.

[1] Water in Armenia. *Armenian Geographic* (2023).

[2] Is tap water safe to drink? *National Geographic* (2023).

[3] Drinking-water quality guidelines. *World Health Organization* (2022-2024).

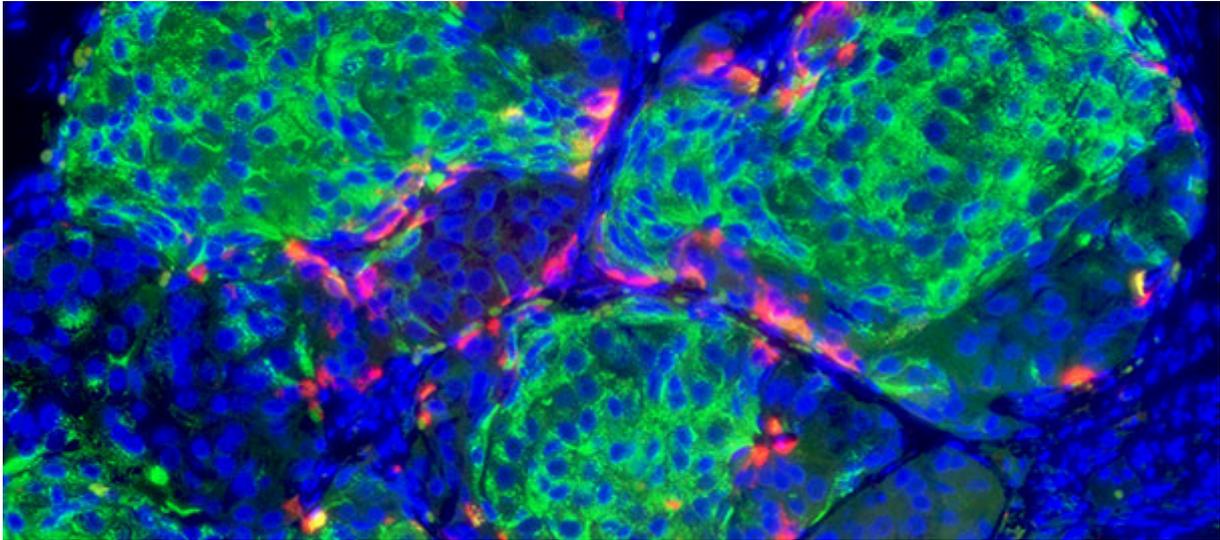
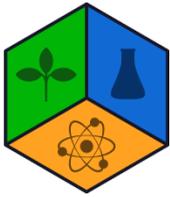


Photo reference: B. D. Colen / Harvard

2. Diabetes Transplants

Type 1 diabetes presents a significant challenge globally, with more than 10 million patients relying on insulin administration for management as there is currently no cure [1]. Insulin therapy is the only available option at the moment, yet all approaches of exogenous injection have severe limitations [2]. One of the most promising avenues for treatment is pancreatic islet transplantation, wherein healthy islets from donors are transplanted into diabetic patients [3-4].

While this approach can restore normal blood sugar levels, one major concern is the immune response of a recipient. To address this issue, current research is focused on developing various methods including encapsulation, cellular modifications, and chemical modifications of the islet surface to prevent immune recognition and attack.

Propose a novel design/method to improve pancreatic islet transplantation for the treatment of type 1 diabetes. Consider factors such as immune compatibility, long-term viability of the transplanted islets, and effectiveness in achieving euglycemia. The design should aim to overcome the limitations of current transplantation methods and offer a more robust and sustainable solution for type 1 diabetes management. Provide a rationale for your proposed approach and consider its feasibility in a clinical setting.

[1] Diabetes. *World Health Organization* (2023).

[2] The epidemiology of type 1 diabetes: Helping to fit the puzzle pieces. *Endocrinol. Diabetes Nutr.* (2015).

[3] Pancreatic Islet Transplantation. *National Institute of Diabetes and Digestive and Kidney Diseases* (2018).

[4] Pancreatic Islet Transplantation in Humans: Recent Progress and Future Directions. *Endocr. Rev.* (2019).

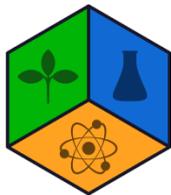


Photo reference: Joe Drivas / Getty Images

3. Why did He leave?

Helium is an inert gas that has found its application in various industries, especially in cryotechnology [1]. Its unique properties make helium indispensable in some of its applications: magnetic resonance imaging scanners, mass spectrometry, leak testing, etc. [2-3].

Currently, helium is produced as a by-product of the liquefaction of natural gas (LNG). However, reserves of natural gas on Earth are not endless, and helium is leaving us [4].

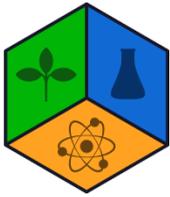
What can we do about it? **Propose** an economically viable industrial method for producing helium in the future that is not a by-product of LNG.

[1] Helium market, Helium One Global (2024).

[2] Helium sell-off risks future supply, Physics World (2010).

[3] Helium Statistics and Information, National Minerals Information Center, USGS.

[4] Why the world is running out of helium? Independent (2010).

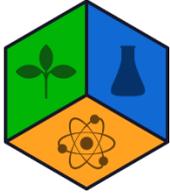


Picture reference: 2024 Electronic Arts Inc.

4. Sim-City

In the era of digital connectivity and remote work, the necessity of densely populated megacities is under scrutiny. Your challenge is to design (simulate) an ideal city, "Sim-City", that overcomes the problems typical of current urban centers, with a focus on scientific and environmental considerations:

- **Climate and Air Quality:** Identify a location that naturally minimizes air pollution. Consider wind patterns, humidity, and weather control techniques like cloud seeding. Explain how these factors ensure clean air and a healthy environment.
- **Resource Availability:** Assess the availability of essential natural resources, such as water and renewable energy. How will these resources support the sustainable development of your city?
- **Air Filtration and Pollution Control:** Propose advanced air filtration systems and technologies to eliminate pollutants, including heavy metals, from the air. Discuss the scientific basis and effectiveness of these technologies.
- **Smart City Technologies:** Describe the implementation of smart technologies to monitor and manage environmental factors, including air quality and energy consumption. How can these technologies enhance the city's sustainability?



5. Harnessing the Sun: Maximizing Solar Energy Capture

Solar energy capture is an area of ongoing research and innovation, with two primary methods currently in use:

- **Photovoltaic (PV) solar panels**, which convert sunlight directly into electricity [1], and
- **Solar thermal-electric power systems**, which use sunlight to generate heat that is then converted into electricity via turbines [2].

Neither method is 100% efficient, and significant amounts of solar energy remain unused. This presents an opportunity to enhance overall efficiency by capturing and utilizing the heat that is not converted into electricity.

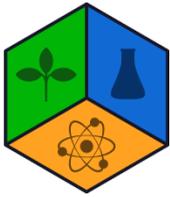
Your task:

1. Compare the efficiency of PV solar panels and solar thermal systems, focusing on the percentage of photon energy transferred into electricity. Consider theoretical limits for PV cells, such as the Shockley-Queisser limit [3].
2. Calculate the coefficient of performance (COP) of various heat capture methods in different environments, considering the temperature of the hot and cold reservoirs.
3. Propose a method for capturing solar energy that integrates both PV solar cells and heat-transfer technology. Analyze where the proposed solution would provide the most cost savings and benefits. Provide a detailed plan for implementing your solution in a location of your choice.

[1] Solar Photovoltaic Technology Basics, US Solar Energy Technologies Office (2024).

[2] Solar explained, Solar thermal power plants, US Energy Information and Administration (2024).

[3] Shockley–Queisser limit.



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6. Happy Meter by *HappyHero*

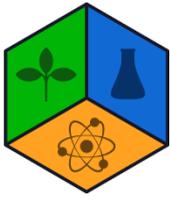
The company HappyHero is developing a mobile application designed to help individuals measure their state of subjective well-being (commonly referred to as "Happiness") and identify correlations between what in life causes frustration and what brings happiness [1].

To achieve this mission, the company is working on collecting data from fitness devices (bracelets, rings, watches) to understand when fluctuations in indicators correlate with negative emotions. One of the key indicators they focus on is HRV—heart rate variability.

However, it is still unknown which easily measurable physiological indicators correlate with positive emotions in humans.

Propose your concept for a device (or software for existing market devices) that can measure positive human emotions based on physiological parameters.

[1] HappyHero. A tool for measuring and increasing human happiness.



2nd block (6 problems)



7. Don't Look Up

Some valuable resources on our planet could be depleted in as little as 30 years, especially the rarest ones necessary to construct computers, smartphones, and other advanced technologies [1-2].

In recent years, significant advancements in technology have made previously unthinkable concepts, such as asteroid mining, a tangible reality. Indeed, asteroids hold vast reserves of these resources and there are several startups spearheading efforts in this field, for example [3].

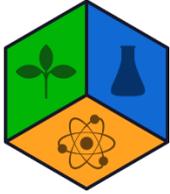
Propose a comprehensive solution, which includes (but is not limited to):

- Identifying/detecting chemical composition of an asteroid;
- Extracting a valuable resource;
- Transporting the resource back to Earth.

[1] Precious metals in peril: Can asteroid mining save us? *Science in the News* (2016).

[2] Asteroid Mining and Why It Makes "Cents" *KMI* (2023).

[3] *AstroForge* (2023).



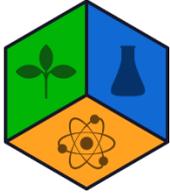
8. BUG Pharma: Gut Microbiome and Mental Health

Depression is a debilitating mental disorder affecting millions worldwide, with existing treatments often falling short in efficacy and sustainability. Recent studies have unveiled a surprising link between microbiota and mental health, opening up promising avenues for innovative therapeutic interventions. Traditional antidepressant medications, while beneficial for many, come with limitations and potential side effects, underscoring the pressing need for alternative treatments. By exploring the microbiota's role in depression and leveraging its potential, we can revolutionize depression treatment and offer new hope to those struggling with this condition.

Despite advances in understanding the microbiota's impact on mental health, there's a critical gap in translating this knowledge into effective therapeutic strategies for depression. Identifying specific bacteria strains and designing a targeted intervention protocol poses a significant challenge. The therapy must address key considerations such as safety, efficacy, and feasibility to ensure its applicability in clinical settings. Additionally, elucidating the mechanisms underlying microbiota-mediated antidepressant effects is essential for optimizing treatment outcomes and minimizing potential risks.

Propose a comprehensive strategy for microbiota-based therapy for depression, i.e., which bacteria strain(s) is(are) selected, rationale behind your choice, and a roadmap for implementing the therapeutic approach.

[1] Gut bacteria-driven homovanillic acid alleviates depression by modulating synaptic integrity. *Cell Metabolism* (2024)

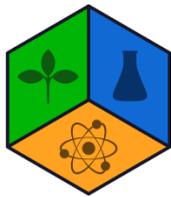


9. Safe Wall-drilling

Drilling into walls poses significant risks, particularly the danger of accidentally penetrating electrical wiring or structural reinforcements such as metal bars (rebar). This not only jeopardizes the safety of the individual performing the drilling but also risks causing property damage or electrical hazards.

Develop an affordable and user-friendly device that enables safe wall drilling, compatible with various drill bits, and capable of integration with existing drills or easily attachable to them. The device should address the following criteria:

- **Safety:** Ensure that the device minimizes the risk of drilling into electrical wiring or structural reinforcements within walls, thereby preventing potential accidents or damage.
- **Versatility:** Design the device to be adaptable to different types of drills and drill bits commonly used for wall drilling tasks.
- **Affordability:** Keep the production cost of the device low to ensure accessibility to a wide range of users, while making sure it remains easy to operate with minimal training.



10. Smart E-tongue

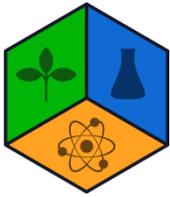
As the standard of living improves, concerns over food safety and potential contaminants are becoming increasingly important. Consumers are demanding higher standards for food quality, freshness, nutritional content, and the absence of allergens. At the same time, food waste has become a global habit issue, with many people buying more food than they need, letting it spoil at home, or taking overly large portions.

A promising solution to address both the challenges of food safety and food waste could be the implementation of electronic tongue (E-tongue) technology. This tool can detect subtle changes in taste, providing early warnings of food spoilage and potential safety concerns. Additionally, it can assess nutritional content and identify possible allergens, ensuring that food not only meets quality and safety standards but also caters to specific dietary needs.

Propose the concept for an E-tongue sensor designed for daily use. This gadget should empower consumers to monitor food quality in real-time, whether at home, in the grocery store, or while traveling. Your presentation of the device should clearly explain which (bio)chemicals can be detected and how the detection process works. Additionally, address how the device will interact with consumers to ensure ease of use and accessibility.

[1] Electronic Tongue—A Tool for All Tastes? Biosensors (Basel) (2018).

[2] Electronic Tongues and Noses: A General Overview Biosensors (2024).



11. iVAP: Indicator of Ventilator-Associated Pneumonia

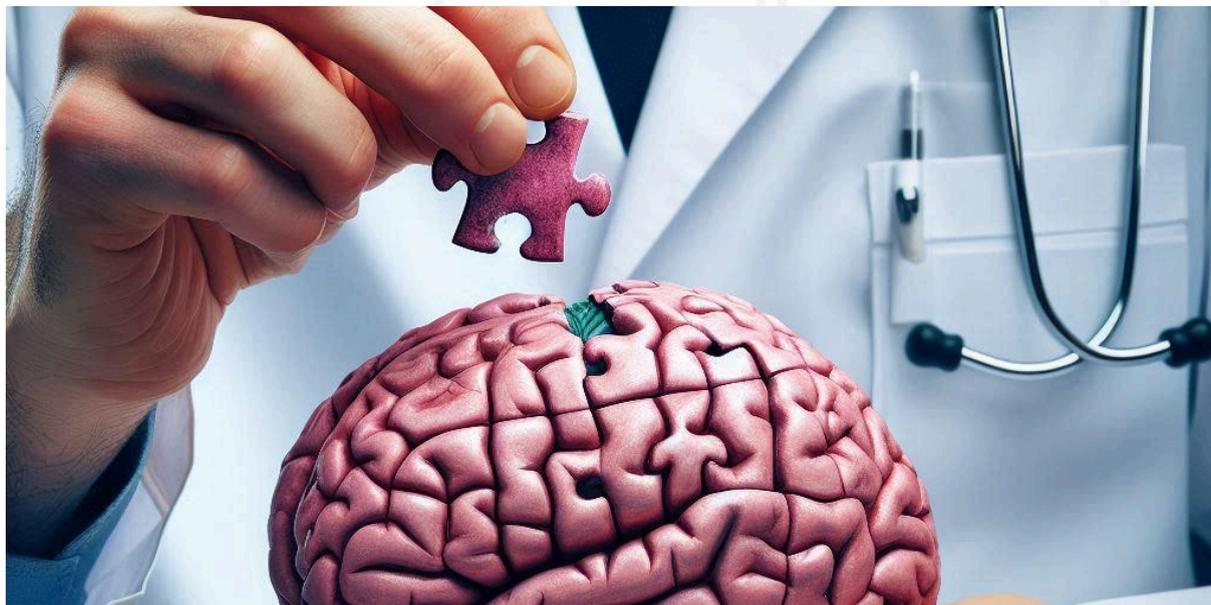
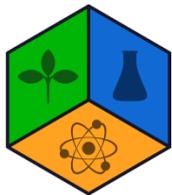
Ventilator-associated pneumonia (VAP) is one of the most common infectious complications in intensive care. VAP occurs in 9-27% of patients on mechanical ventilation, leading to longer ICU stays, increased healthcare costs, and higher mortality rates [1].

Current diagnostic methods for VAP often delay targeted treatment, worsening patient outcomes. The symptoms of VAP can be nonspecific and overlap with other pulmonary conditions, complicating early diagnosis [1].

Propose a new, effective, and rapid bedside method for early diagnosis of VAP. This method could involve using biomarkers in the airways, genomic and proteomic analyses, or artificial intelligence to analyze ventilator data and monitor vital signs [2].

[1] Ventilator associated pneumonia. *BMJ* (2012);

[2] Exhaled Breath Metabolomics for the Diagnosis of Pneumonia in Intubated and Mechanically-Ventilated Intensive Care Unit (ICU)-Patients. *International Journal of Molecular Sciences* (2017).



12. Design of Targeted Protein Degradator

Alzheimer's disease (AD) is a progressive, neurodegenerative disorder that impairs cognitive function and causes a decline in memory, thinking and reasoning. Current therapeutic strategies help to maintain mental function and slow or delay the symptoms of AD but not address the causes of the disease. The current hypothesis of AD development is connected to the accumulation of abnormally folded proteins such as amyloid beta protein ($A\beta$) in the brain and hyperphosphorylation of tau protein, which disrupt neuronal function and lead to cell death [1].

Therapeutic targeting of misfolded and aggregated protein is a promising area of research. In recent years, biotechnology industry is developing the concept of targeted protein degradation (TPD) as a powerful approach for destroying classically "undruggable" disease-causing proteins with using cellular protein degradation machinery. TPDs are small molecules that hijack cellular degradation processes - the ubiquitin–proteasome and autophagy–lysosome pathways [2].

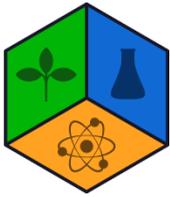
Design your targeted protein degrader to cure Alzheimer's disease:

- Choose the target, propose the structure of your TPD and explain the mechanism of action;
- Suggest the cost-effective synthesis scheme of your TPD considering the cost and availability of reagents;
- Propose a delivery method to transport your TPD to brain and justify your choice.

[1] Role of Amyloid- β and Tau Proteins in Alzheimer's Disease: Confuting the Amyloid Cascade. *J Alzheimers Dis.* (2018).

[2] PROTAC targeted protein degraders: the past is prologue. *Nature Reviews Drug Discovery* (2022).

[3] Treatment of Alzheimer's by PROTAC-Tau Protein Degradation. *ACS Med Chem Lett.* (2019).



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Additional information

Unless otherwise noted, images were generated using Microsoft Copilot AI.

Please, be careful to work through every problem. The problems are divided into 2 blocks. The day, which each of the blocks will be played at, will be announced not later than 3 days before the Grand final. Remember that you may refuse to solve any one problem in each block. No extended solution (*.doc) is needed.

If you have any questions regarding the presented information, please do not hesitate to contact Teams' coordinators Anastasiia and Dmitrii via e-mail: tournament@scitourn.com.