REAL TIME

TECHNOLOGY ASSESSMENT

Dr. Brandiff R. Caron

iGEM CONCORDIA

What is the Real Time Technology Assessment (RTTA)?

Dr. Brandiff R. Caron

The RTTA was developed at the Center for Nanotechnology in Society at Arizona State University (CNS-ASU) mandating the integration of research on societal, ethical and environmental concerns with nanotechnology research and development.

Whereas conventional technology assessments focused on generating information intended to allow decision makers to react to emerging technologies, RTTA focuses on improved decision processes that can enable learning, cultivate deliberation, signal emerging problems, and allow more conscious choice as research and innovation occur. The focus is on opening up the innovation process, rather than managing it after-the-fact.

In terms of timing, RTTA demands to be implemented at a very early stage in the evolution of a new area of technology, before social outcomes are well understood, and economic and political interests are reified.

Guston, D. & Sarewitz, D. 2002. "Real-Time Technology Assessment," Technology in Society 24 (2002) 93-109.

Dr. Brandiff R. Caron

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iGEM (International Genetically Engineered Machines) Concordia

A passionate team of curious young scientists, and engineers, proud to be affiliated with the Centre for Applied Synthetic Biology and Canada's only academic Genome Foundry. iGEM Concordia employed the RTTA process for two years in a row with the consultation of Dr. Caron.

It is a process that undoubtedly strengthens our project and which we look forward to!

"An ability to apply professional ethics, accountability, and equity."

How to use the RTTA

By Dr. Brandiff R. Caron & adapted by iGEM Concordia

The Real Time Technology Assessment is a four phase process.

1. Analogical Case Study
2. Mapping Contemporary Practice
3. Public Perception and Early Warning
4. Technology Assessment and Choice

Each phase involves research followed by a brief write up summarizing the findings. At iGEM Concordia we like to share the work amongst the team, assigning each phase to a small group.

At the end of the RTTA, we have a concise document to defend our project's development and applications.

The best part is sitting down and reviewing the findings together through open dialogue.

Learning outcomes:

Communication Skills: an ability to communicate complex bioengineering concepts within the profession and with society at large.

Impact of BioEngineering on Society and the Environment: an ability to analyze social and environmental aspects of bioengineering activities. Such abilities include an understanding of the interactions that bioengineering has with the economic, social, health, safety, legal and cultural aspects of society.

Ethics and Equity: an ability to apply professional ethics, accountability and equity.

Professionalism: an understanding of the roles and responsibilities of the professional bioengineer in society, especially the primary role of protection of the public and the public interest.

Remember E.L.S.E.I.
Ethical, Legal, Social, & Environmental Implications

Analogical Case Study

1

By Dr. Brandiff R. Caron

Research a relevantly analogous past example of an innovation similar to your chosen project. Analogous meaning comparable in certain respects or similar to your project. Develop 1-2 pages while paying particular attention to:

- Identifying and describing an analogous case study

- Who else has responded the innovation of interest (your project idea) in the past? What types of responses have they used, and what avenues have they selected for those purposes?

- Has your team drawn appropriate links between the analogical case study and your project with regard to their professional responsibilities – moral, legal & social?

- Has your team developed analogies and frameworks for understanding and anticipating societal response to your own innovations?

2

Contemporary Practice

By Dr. Brandiff R. Caron

Research and assess current Research & Development (R&D) activities at regional, national, and international levels within the area of innovation that your iGEM project falls into. The unit of assessment can vary from a single laboratory to an entire field of innovation but, whatever the scale, take some effort to map the resources and capabilities of the enterprise necessary to identify key R&D trends, major participants and their roles, as well as organizational structures and relations. Develop 1-2 pages while paying particular attention to:

- Has your team identified current professional standards and R&D practices making use of appropriate research techniques?

- Has your team drawn appropriate links between contemporary practice and their project?

- Has your team used this information to identify existing knowledge gaps and the need for additional data when designing for optimal social, ethical and environmental impact?

Public Perception of Technology 3

By Dr. Brandiff R. Caron

The public perceptions of technology aspect of the RTTA requires empirically grounded, research-based strategies for enhancing the quality of technologies through the identification and incorporation of public perceptions of scientific, technical, and social developments within a particular area of innovation. Develop 1-2 pages paying particular attention to:

- Perform a content analysis of major media sources for public information about the innovation.

- Research and assess the public concerns about, and aspirations for, the development and application of the innovation.

- Survey research to identify public reaction to media portrayals of the innovation and to track changes in public attitudes about developments in the innovation.

- Map the ethical, legal, social, and professional concerns for your particular project in the media (newspapers, broadcasts, social media, blogs, television, movies, radio, podcasts and more).

Technology Choice and Assessment

4

By Dr. Brandiff R. Caron

This document summarizes the findings of the last three phases. Develop 1-2 pages while paying particular attention to:

-Identifying choices made through the various iterations that had ethical, legal, and/or social implications.

-Identifying how choices have been influenced by the knowledge acquired through the application of the techniques described in the Real-Time Technology Assessment methodology.

-Reflecting on and explicitly demonstrating iterations, in the process followed, where ethical, legal, environmental, economic and/or social implications were identified and addressed. Evaluate the role of real-time technology assessment in your own (and other similar) projects.

-What choices made as to your project were affected by this research?

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TECHNOLOGY ASSESSMENT

By iGEM Concordia

iGEM CONCORDIA

ASTROYEAST 2020

Project Description

The biomanufacturing of food, drugs, and biomaterials in outer space is necessary for humans to venture into the cosmos and colonize extraterrestrial bodies. Advances in synthetic biology enable the sustainable production of these resources on Earth. However, in-space bioproduction, for which maintaining cultures in bioreactors for extended periods is essential, has proved challenging. Microgravity induces global changes in gene expression profiles, triggering a stress response in cells.

For example, *Saccharomyces cerevisiae*, a model organism and biomanufacturing chassis, exhibits a microgravity-induced stress response characterized by aberrant cell polarity, budding, and separation; which affects cell growth and productivity in space. We are eager to design a solution to alleviate this undesirable stress-response, to ensure the future of in-space biomanufacturing and exploration.

Our solution is AstroYeast, which consists of a database and reporter strains for microgravity that enable us to make space-compatible strains of yeast. We have designed a database compiling microgravity-induced gene expression changes in *S. cerevisiae* and other model organisms. The database will be available via open source software to support the community and assist researchers in engineering microorganisms for space bio-manufacturing.

This database contributes to the creation of a microgravity-induced stress reporter in *S. cerevisiae* that indicates when microgravity is affecting the cell. We will build genetic circuits using one or more genes that have altered expression levels in microgravity. Candidate reporter strains will be tested and characterized in simulated microgravity conditions on Earth and in space.

The database and reporter strain are the foundation for the culminate design of *S. cerevisiae* strains that are resistant to microgravity-induced stress. For example, the development of space-compatible yeast strains that could produce medications or nutrients, continuously, in space. This will be done in a high-throughput manner either by strain adaptive evolution, or genome-wide overexpression and knockdown screens. We are designing our own microgravity simulator for the experiments. AstroYeast enables the creation of a novel in-space microbial biomanufacturing chassis, advancing the fields of astrobiology and synthetic biology in space!

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Findings

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Analogical Case Study

by Brian Baxter, Nhi Hoang Nguyen and Labrini Vlassopolous

Analogical Case:
Tirumalai, M. R.; Karouia, F.; Ott, M. The adaptation of Escherichia coli cells grown in simulated microgravity for an extended period is both phenotypic and genomic, 2017.

The 2017 study performed by Dr. Tirumalai and associates sought to adapt e. coli cells to low shear modeled microgravity (LSMMG). E.coli much like yeast is an organism which has proven especially inducible to genomic changes when provided a sufficient selective advantage.

The methodology for generating a microgravity adapted e.coli strain was to continuously grow the strain under LSMMG for 1000 generations in a rich medium. After the generation threshold was reached genomic sequencing was performed in order to find the adaptation in the new organism. In order to show that the adaptations experienced by the strain were better adapted to microgravity they grew the adapted strain which was lac positive in the same dish as a non adapted control strain in the conditions of microgravity, these were referred to as 'growth competitions'. The research was able to show that adapted strains readily outcompeted those which were non adapted, moreover, this competitive advantage was maintained in large degrees when exposed to cycles of erasure.

There are many similarities which can be observed between this project and our own, primarily when focused on determining the effects of microgravity. The study cared less about the specific gene behaviour, as our project intends to, but rather the readiness of the organism to outcompete control strains in microgravity. Their design might be simpler to perform while providing results which are decidedly concrete. The design of our project overlaps in the goal, the simulated microgravity and the sequencing.

Being published in the leading scientific journal Nature, the paper has received a lot of attention and responses from the public. Statistically, the readers mostly are students and researchers (72%). A smaller percentage of practitioners like doctors or librarians and other science communicators (journalists, bloggers or editors) are also interested in the paper (29%) (1). The majority of professionals who cited the paper used the scientific finding to further support and evaluate their work on similar projects.

For instance, the research paper Effects of spaceflight and simulated microgravity on microbial growth and secondary metabolism analyzed this study along with other similar works on effects of different strains of bacteria on simulated gravity to draw a conclusion on how differences in the microenvironment results in the diverse responses of bacteria (6).

On the other hand, many news stories, blogs or posts on social media mentioned this paper to inform, alert about a more challenging space trip given the fact that bacteria, which is a potential pathogen, will grow better, arise mutations and become more resistant to antibiotic in micro-g, of which article Experiments Show Bacteria Grow More Lethal And Antibiotic-Resistant in Space is an example (11). Additionally, other research papers and articles used the information to suggest further research for a better protection for astronauts from biofilms and the possibility of human adaptation in space (4,8). It is not hard to realize that the paper has received such responses because it dealt with a familiar topic in modern science that is of great interest: space travel and bacteria adaptation, and also because it questioned and paved the way for further studies in this area to improve the methodology, simulate a better real space conditions with radiations and other stressors, and solve the problem of increasing growth rate of bacteria in space.

Seeing as this paper served to increase general information rather than to be a living bacterial 'tool', the professional responsibilities held are concerning the ethical and moral side. No legal considerations were needed.

The three primary areas of concern with evolution of microorganisms are gaining antibiotic resistance, pathogenicity, and the organisms accidental release followed by outcompeting existing life. Seeing that this study and our research focuses on an organism optimized for space it is unlikely that the adapted organism is a risk to outcompete other organisms on earth, therefore, the first two risks are the focus.

Analogical Case Study

by Brian Baxter, Nhi Hoang Nguyen and Labrini Vlassopolous

Possible gain of antibiotic resistance was tested for by exposing the microorganism to antibiotics ensuring they remained effective. No adaptation for antibiotic resistance was gained. Testing for an adaptation which promotes virulence was harder to determine as it can be triggered from a variety of factors and evidence of its presence also is varied. The method used was to scan for expression of known genes associated genes associated with virulence in E.coli, as well as to scan for the expression of genes which allow for the avoidance of the immune system. Should the research expand to the point where experiments left the lab environment it would require researchers to create a strict methodology to stop “forward contamination”.

Now let us explore the societal responses to the research in question. Given this study did not intentionally alter the organisms involved but instead studied the effects of microgravity on the responses of the cells over 1000 generations, no clear framework was discussed as to how their findings would be received by society in the published article. No parameters or limits were put in place to determine to what degree mutations are ethical or unethical, which would strongly influence the public's perception and feeling of dystopian danger. Moreover, radiation effects on the bacteria can increase mutation rates. As compared to astronauts who may experience negative effects from changes in their immune system responses, so too can the bacteria. Protecting the bacteria from the radiation was not discussed. The evolution of undesirable properties was said to be of concern for the purposes of the end goal with no regard to how long the bacteria would be exposed to the stressors because they cannot feel pain (9). As such, the three ethical Rs do not apply here. The study did look into how their work could become an issue if things went wrong, an addition which likely helped its entry into Nature.

Space exploration has long brought people together. A lot of money is spent on space research. Money, some may say, that would be better spent solving global problems (7). Coupled with increasing scientific skepticism in the population, space research is not exclusively important for building future independent and autonomous colonies. Although that is the most likely future for humanity (2), space research and space technology help us understand the Earth in ways we have not yet been able to. It has helped shape our mindsets, our attitudes and our stories (3). Recently, space research and exploration is a very attractive avenue to consider for humanity's future due to increasing climate deregulations and unpredictable weather shifts, increasing number of people and a decreasing amount of affordable and available resources (9). There is an urgency to understanding microgravity's impacts not only on humans but other organisms in the hopes of creating applications and technologies that can allow space exploration to reach new heights through the acquiring of self-sufficient technologies and ways of doing things in deep space. Our project falls into this category of potentially expanding humanity's reach in outer space and allowing more possibilities for prolonged microgravity research and applications.

References

1.Almetric. (n.d.). Retrieved from https://www.altmetric.com/details/20417202

2. CSA. (2019) The future of space exploration:beyond the International Space Station. Retrieved from: https://www.asc-csa.gc.ca/eng/astronomy/moon-exploration/the-future-of-space-exploration-beyond-the-international-space-station.asp

3.Dick, S.J., (2005) Societal Impact of the Space Age. NASA. retrieved from: https://www.nasa.gov/exploration/whyweexplore/Why_We_09.html

4.Francois. C., Cedric. S., Audrey. B., (April, 2020). Human Adaptation to Deep Space Environment: An Evolutionary Perspective of the Foreseen Interplanetary Exploration. Retrieved from https://www.frontiersin.org/articles/10.3389/fpubh.2020.00119/full

5.Gronstal,A. NASAAstrobiology. Retrieved from https://astrobiology.nasa.gov/news/putting-the-ethics-into-planetary-protection/(accessed Jul 28, 2020).

6. Huang, B., Li, D., Huang, Y. et al. Effects of spaceflight and simulated microgravity on microbial growth and secondary metabolism. Military Med Res 5, 18 (2018). https://doi.org/10.1186/s40779-018-0162-9.

7.Keane, D. (2019) Space is about to get a funding boost but there are ethical questions to consider, experts say. ABC Radio Adelaide. Retrieved from: https://www.abc.net.au/news/2019-10-19/should-space-travel-be-a-priority-in-an-era-of-climate-change/11610908

8.Kyle L., Jose M., Bharat B., Nora H. and Sandip P., (June 2020). Biofilms—Impacts on Human Health and Its Relevance to Space Travel. Retrieved from https://www.mdpi.com/2076-2607/8/7/998/htm

9. SenCanada. (n.d.) Do Invertebrates Feel Pain? Senate of Canada. retrieved from https://sencanada.ca/content/sen/committee/372/lega/witn/shelly-e.htm#:~:text=Because%20bacteria%20are%20not%20thought,is%20capable%20of%20feeling%20pain.

10.Tirumalai, M. R.; Karouia, F.; Ott, M. The adaptation of Escherichia coli cells grown in simulated microgravity for an extended period is both phenotypic and genomic, 2017.

11.Vikrant. M. (July, 2020). As if space wasn't dangerous enough, bacteria become more deadly in microgravity. Retrieved from https://theconversation.com/as-if-space-wasnt-dangerous-enough-bacteria-become-more-deadly-in-microgravity-141053

Contemporary Practice 2

by Gabriel Aguiar-Tawil, Natasha Letourneau, Asif Iqbal

Space exploration is the next step of human expansion. As humans continue to use the Earth's natural resources, humans will eventually be faced with the fact that they must become space-faring. To do so, humans must have the resources to do so safely, and efficiently enough that the benefits outweigh the costs. An avenue for this is the use of microorganisms such as yeast or bacteria as sources for medicine, materials, biofuels, and food. Due to the magnitude of this issue, many groups are researching possible solutions, and they vary from federal space agencies such as NASA, to smaller groups such as undergraduate led iGEM teams.

NASA is currently undergoing an experiment called BioNutrients which focuses on using yeast as a nutritional source. Researchers are focused on the production of beta carotene and zeaxanthin, which are antioxidants necessary for proper eye health. However, the production of these nutrients is not their only focus. A large part of their project pertains to the viability of yeast as a chassis for bioproduction after being frozen, thawed out, and grown repeatedly as they would during a real mission. Although their project primarily focuses on nutrition in space, they are also taking remote communities on Earth into consideration. This adds a social aspect that otherwise would not be there, through allowing these communities to have access to nutritional options that they would normally not have (1).

NASA has also conducted research on ways to make bread in space by customizing ways to bake in the absence of gravity (4). This particular project was under the Getaway special program that offered organizations to conduct small experiments in the space shuttle. As we all know, the three ingredients that are necessary to make bread are yeast, water, and flour. The shelf-life of the yeast can be one year, if stored inside a refrigerator and flushed with nitrogen. However, by genetically engineering yeast and obtaining a library of mutant strains, it is possible to know which genes respond to microgravity. From this, it is possible to know which strain is best suited for spaceflight and prolonging the life span of the yeast. Thus allowing astronauts to broaden their diet.

Space has been a topic used by several other iGEM teams as the basis of their projects.

Contemporary Practice

by Gabriel Aguiar-Tawil, Natasha Letourneau, Asif Iqbal

The 2019 Brown Stanford and Princeton team tackled the problem of pharmaceuticals in space. To avoid having to bring along a large amount of pharmaceuticals, all of which have their own shelf-life, the team engineered Bacillus subtilis to produce insulin, teriparatide, and hG-CSF. They also adapted this to a cell-free system that used a microfluidics chip to control the reactions (2). The 2017 University of Calgary team developed a way to turn human waste into bioplastics. This was done by using human waste as a feedstock for their engineered E.coli strain, which in turn produced bioplastics that could be used to 3D print tools and building materials in space. They tackled two problems using this approach; the management of human waste in space, and the need for plastics in space (3).

None of these projects try to do the same thing as us, that being the production of a microgravity tolerant strain of baker's yeast. However the one thing that they all have in common is the fact that their, and our, collective goal is to get humans to become the space-faring species that we have dreamed about for a long time.

References

1- Bionutrients. (2019). What is BioNutrients?. NASA.https://www.nasa.gov/ames/bionutrients

2- iGEM University of Calgary. (2017). Our Project. iGEM Organization. http://2017.igem.org/Team:Calgary/Description

3- iGEM Brown, Stanford, Princeton. (2019). Project Description. iGEM Organization. https://2019.igem.org/Team:BrownStanfordPrinctn/Description

4- NASA. (1987) Goddard Space Flight Center The 1986 Get Away Special Experimenter's Symposium; p. p 119-126 https://ntrs.nasa.gov/search.jsp?R=19870010886

Public Perception

by Grecia Olano O'brien, Evelyn Huaman, Amin Nikpayam

Content analysis When it comes to space exploration, it is common practice for space agencies to carry out a series of consultations that include policy makers, members of the scientific community as well as the general public [1]. The idea behind these consultations is to present space exploration as a societal project that seeks to benefit all of humankind [1].

Bodies such as the European Space Agency (ESA), the National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA), among others, often invite the public and journalists to take part in their events which include, but are not limited to media conferences [2]. Moreover, space agencies count with their own media relations teams responsible for creating and distributing press releases and reports. These documents are readily available online for anyone to read and share [3].

Furthermore, agencies have developed web portals specifically designed to showcase their work and initiatives. For example, the Canadian Space Agency (CSA) offers a myriad of information resources to inspire young Canadians and to educate the public about life in space [4]. The CSA also organizes all sorts of podcasts and webinars [4]. Likewise, NASA offers resources for three separate audiences: the media, educators, and students [5] [6].

With regards to the production of bionutrients, NASA has taken some steps to keep the public informed about the nutritional challenges faced by astronauts [7]. This independent agency of the U.S. Federal Government is trying to shed light on the importance of potential applications of synthetic biology for future deep space missions [7]. What is more, NASA's Ames Research Centre has disclosed key insights on one of their synthetic biology projects: BioNutrients [8]. The centre briefly explained how micro-organisms can be used to produce sustainable food sources that will help maintain human health in space [8].

In 2016, NASA discovered that they owned approximately 300 accounts across eight different platforms: Facebook, Flickr, Instagram, LinkedIn, Pinterest, Tumblr, Twitter, and YouTube [9]. The agency is in the process of consolidating their social media presence. Nonetheless, NASA continues to allow mission-specific and project-specific social media accounts to exist. Currently, their technological advancements in the production of bionutrients are shared on their NASA Technology Facebook account and on their official website [10].

Other major media sources available to public include digital platforms that share content discussing innovations in the food technology sector. For instance, Food Unfolded has published a couple of articles on space food technology [11]. Well-known academic institutions such as the Massachusetts Institute of Technology (MIT) have also released content that highlights how scientists are hoping to bioengineer solutions that will help support life in space [12]. Overall, synthetic biology is being portrayed as an emerging discipline with untapped potential.

Public concerns on aspirations, development, and application of the innovation

Before going into details regarding the public concerns surrounding the bioproduction of nutrients, it is important to point out that public perceptions shift over time and that they are affected by environmental factors that go beyond bioengineering itself [13]. It is equally imperative to recognize that the process of bioengineering micro-organisms has not been covered extensively in non-scientific publications in a way that would enhance the general public's understanding of this process or that would clearly convey the benefits of this innovation. For this reason, it is likely that the public perception of the bioengineering of space-compatible micro-organisms is tied to the overall public perception of space exploration.

The constant press releases and social media posts by space agencies are without a doubt playing a significant role in shaping the public perception of space exploration technologies. Given the agencies' continuous updates and extended social media presence, it could be argued that they are attempting to control the narrative surrounding space programs. On NASA's end, there is also a strong emphasis on ensuring that the public perception of space exploration activities remains favourable amongst youths [6].

Public Perception

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Research has shown that scientific pursuits associated with space missions are "appealing to the public on a psychological level [14]." These pursuits tend to be perceived as innovative activities closely linked with a country's optimism, can-do attitude, and national pride [14]. It is safe to assume that if the bioproduction of nutrients is continued to be presented as a key driver for innovation, public perceptions will remain favourable. Yet, it is worth noting that there exists some level of public discomfort with initiatives related to space research due to the high costs typically associated with space programs [14]. Once again, these perceptions could be carried over to bioengineering projects.

The use of genetically modified organisms has been well received in the field of medicine where biotechnology and genetic engineering have provided ways to produce new drugs that alleviate suffering and save human lives [15]. Space-compatible bionutrients could be perceived in an equal favourably manner if a greater emphasis is placed on communicating how these bionutrients would help keep astronauts healthy during their space travels [16].

Survey research

Public opinion polls about space exploration in general are carried out by internal space agency divisions as well as external parties such as market research companies and universities [17]. Polls discussing and tracking public perception regarding the specifics bioengineering of space-compatible micro-organisms are yet to be conducted.Public opinion polls conducted by Ipsos have shown that 80% of Americans believe that space exploration activities promote scientific discoveries, while 77% find that space missions inspire youths. Unsurprisingly, over two-third of the Americans believe space exploration is a necessity [17]. Canadians are also on board with the opportunity to pursue space exploration. "84% of Canadians are supportive of developing the country's space sector – a 20 point increase from a 2007 [18]." Interestingly enough, "42% of Canadians believe that Canada is falling behind other countries when it comes to achievements in space [18]."

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Ethical, Legal, Social, and Professional Concerns

The process of engineering bionutrients brings forward the “playing God” argument often used by those opposed to the production of genetically modified micro-organisms [18]. In the past, critics of synthetic biology have used this argument to imply that bioengineers have no problem using their power and knowledge to disrupt nature. They state that nature has an inherent value itself and that tampering with it is morally questionable [19]. In addition, ethical concerns surrounding unanticipated effects of bioengineering micro-organisms should be addressed [20]. One way to mitigate general ethical concerns is to promote the application of bioethics principles explicitly designed to assess and manage these risks [21] [22].

Legally, bionutrients could raise concerns regarding intellectual property, regulation of testing, and applications of this technology outside the context of space exploration. From a social perspective, to some, it seems unreasonable to allocate funding for space-related bioengineering projects when society as a whole has not yet been able to find solutions to existing global challenges such as pollution, unemployment, and poverty, to name a few [14].

Finally, from a professional standpoint, some members of the public, along with geneticists and bioengineers can argue that there are still many scientific frontiers to be explored on Earth before venturing into space [14]. Additionally, assembling a team of experts in the context of in-space production of bionutrients will prove to be a challenging task as there is a limited number of researchers who possess the expertise necessary to proceed with this type of project.

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References

[1] The European Space Agency, "ESA polls stakeholders to inform its long-term exploration strategy," 19 December 2006. [Online]. Available: https://www.esa.int/About_Us/Corporate_news/ESA_polls_stakeholders_to_inform_its_long-term_exploration_strategy. [Accessed August 2020].

[2] National Aeronautics and Space Administration, "Space flight Forum," 29 May 2019. [Online]. Available: https://forum.nasaspaceflight.com/index.php?topic=43382.60. [Accessed August 2020].

[3] The European Space Agency , "Press Releases," 2020. [Online]. Available: https://www.esa.int/Newsroom/Press_Releases. [Accessed August 2020].

[4] Government of Canada, "Canadian Space Agency," 16 January 2020. [Online]. Available: https://www.canada.ca/en/space-agency.html. [Accessed August 2020].

[5] National Aeronautics and Space Administration, "For Media," 14 April 2020. [Online]. Available: https://www.nasa.gov/news/media/info/index.html. [Accessed August 2020].

[6] National Aeronautics and Space Administration, "NASA STEM Engagement," 2020. [Online]. Available: https://www.nasa.gov/stem. [Accessed August 2020].

[7] National Aeronautics and Space Administration, "Space to Ground: Open for Business: 06/14/2019," 14 June 2019. [Online]. Available: https://www.nasa.gov/mediacast/space-to-ground-open-for-business-06142019. [Accessed August 2020].

[8] National Aeronautics and Space Administration, "From Baker's Yeast to Nutrients, New Experiment Heading to Space Station," 2019 April 16. [Online]. Available: https://gameon.nasa.gov/2019/04/16/from-bakers-yeast-to-nutrients-new-experiment-heading-to-space-station/. [Accessed August 202].

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[16] National Aeronautics and Space Administration, "Engineering essential nutrients on demand next development of space farming," 18 July 2019. [Online]. Available: https://www.nasa.gov/feature/engineering-essential-nutrients-on-demand-next-development-of-space-farming. [Accessed August 2020].

[17] Ipsos, "Attitudes Toward Space Exploration," 10 July 2019. [Online]. Available: https://www.ipsos.com/en-us/news-polls/cspan-space-exploration-2019. [Accessed August 2020].

[18] Ipsos, "Canadians' Support and Enthusiasm for Development in the Space Sector is Taking Off," 20 September 2018. [Online]. Available: https://www.ipsos.com/en-ca/news-polls/space-sector-taking-off. [Accessed August 2020].

[19] P. Dabrock, "Playing God? Synthetic biology as a theological and ethical challenge," Systems and synthethic biology, vol. 3, pp. 47-54, 2009.

[20] H.-J. Link, "Playing God and the Intrinsic Value of Life: Moral Problems for Synthetic Biology?," Science and engineering ethics, vol. 19, 2012.

[21] P. Brey and S. Nagel, "Bioengineering," Springer Science, 2015.

[22] G. Bugliarello, "Bioengineering Ethics: The Ethics of the Linkage Between Engineering and Biology," in National Research Council (US) Committee on the Experiences and Challenges of Science and Ethics in the United States and Iran, Washington, 2003.

[23] M. El Karoui, M. Hoyos-Flight and L. Fletcher, "Future Trends in Synthetic Biology," Frontiers in Bioengineering and Biotechnology, 2019.

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[9] National Aeronautics and Space Administration, "NASA Science Social Media Consolidation FAQ," [Online]. Available: https://science.nasa.gov/researchers/nasa-science-social-media-consolidation-faq. [Accessed August 2020].

[10] National Aeronautics and Space Administration, "NASA Technology," 16 April 2019. [Online]. Available: https://www.facebook.com/NASATechnology/photos/a.327097270672838/2169988359717044/?type=3. [Accessed August 2020].

[11] Food Unfolded, "Space Food Technology - Why we haven't been to Mars yet," 13 September 2019. [Online]. Available: https://www.foodunfolded.com/how-it-works/space-food-technology-why-we-havent-been-to-mars-yet. [Accessed August 2020].

[12] K. Foy, "Scientists look to synthetic biology and 3-D printing for life support in space," 26 July 2019. [Online]. Available: http://news.mit.edu/2019/scientists-look-synthetic-biology-3-D-printing-life-support-space-0726. [Accessed August 2020].

[13] Britannica, "Components of public opinion: attitudes and values," [Online]. Available: https://www.britannica.com/topic/public-opinion/Components-of-public-opinion-attitudes-and-values. [Accessed August 2020].

[14] Encyclopedia, "Public opinion about space exploration," 19 August 2020. [Online]. Available: https://www.encyclopedia.com/reference/culture-magazines/public-opinion-about-space-exploration. [Accessed August 2020].

[15] Lumen, "Geneitc engineering products," [Online]. Available: https://courses.lumenlearning.com/boundless-microbiology/chapter/genetic-engineering-products/. [Accessed August 2020].

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by Lancia Lefebvre

AstroYeast are space-compatible yeast strains- imagine mini cellular factories- for the biomanufacturing of nutrients, in space. We have developed AstroBio, a differential gene database for expression in microgravity conditions, to assist us in our research and development. We have evaluated the ethical, legal, social and environmental implications of our two-year project through the use of the Real Time Technology Assessment framework. Here we outline our technological choices for AstroYeast, as influenced by this framework. For decisions made with respect to AstroBio please refer to the Engineering Success component of our project.

Our technology consists of bioengineered yeast strains for in-space manufacturing. Why yeast? As stated in the Analogical Case Study component of this framework, yeast are well-suited to bioengineering as they have "proven [to be] especially inducible to genomic changes when provided a sufficient selective advantage (1) ". Yeast a well-suited microorganism for our adaptive evolution experiments. In addition, yeast are small and reproducible- astronauts can take a small vial from Earth and culture AstroYeast nutrients on the spaceship (5). They are also well-characterized with the whole genome being sequenced and many databases, such as NCBI or Yeast Genome, available to access this information. It is known that yeast is viable in outer space and a bonus is the high homology of yeast with humans (5). Insights gained as to the mechanisms affecting the cell in microgravity could contribute to human health studies.

A few areas of concern came to light in our Analogical Case Study. First, the ethics of inducing mutations in microorganisms and second the pathogenicity of bioengineered microorganisms, combined with the possibility of accidental release into the environment.

With respect to inducing mutations, our experiment will make use of adaptive evolution which submits the cells to a stress continuously after which we select for tolerant candidates. In our interview with microgravity yeast researcher, Dr.Corey Nislow, this approach was validated:

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" I think adaptive evolution is much more in the spirit of Omics in that you're letting the cell tell you what it needs to survive in that condition (2)."

Adaptive evolution also has the benefit of seeming more 'natural' to the general public as it involves less direct editing of the genome. Instead it allows the cell to decide what it needs. The Analogical Case Study also brought to light the ability of radiation to accelerate mutations. Dr. Nislow is sending a complete yeast collection to study the effects of radiation in yeast on the next lunar mission, *Artemis 1*, therefore more concise findings will be available before our strains would be launched. In addition, he adds that,

> **" The radiation that you experience in Lower Earth Orbit is pretty modest. I think you're safe. We're focusing 90% of our radiation experiments on good ground control experiments (2)."**

The effects are minimal and, in Dr.Nislow's opinion, negligible for our case.

With respect to pathogenicity and accidental environmental release, yeast is a well-studied organism with robust laboratory protocols for genetically edited strains here on Earth and in space (5). The baker's yeast, *S.cerevisiae*, we are working with has low pathogenicity, it is commonly used in making bread, wine and beer. It is GRAS (Generally Regarded As Safe). We feel confident that in following these established protocols that our strains can be isolated from environmental contamination. In addition kill-switches or safety systems can be engineered into the genome, which are activated upon undesirable release.

Yeast are well- characterized microorganisms, with a fully-sequenced genome and they do not uptake other DNA as readily as bacterial chassis can. It is also already used extensively in laboratories and in fermentation industries. This facilitates the application and implementation of successful strains. As Scot Bryson of Orbital Farm said,

> **"Yeast is great for the scale up process because you don't have to go and invent a new bioreactor. And that's a huge technology risk, that's a huge length of time to develop that. Huge amounts of engineering and money and capital to make that happen (3)."**

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A small vial (~3ml) of AstroYeast could be sent up to the ISS and cultured in a bioreactor to produce more when needed. This provides a reproducible nutrient source. Furthermore, the production system has the potential to be sustainable by integrating our future bionutrients production system into current waste streams, whether in the spaceship or habitat, as suggested by our implementation advisor, Scot Bryson CEO and Founder of Orbital Farm.

In the second phase of the RTTA, Contemporary Practice, we saw microorganisms being used to produce nutrients, or pharmaceuticals, as a contribution to human's becoming a space-faring species. NASA's Bionutrients program is the most similar with respect to our research. They are bioengineering yeast to produce nutrients, such as carotenoids, for astronauts. We are inspired by their endeavours and appreciate that we are building a space-compatible chassis which can be applied to optimize applications such as theirs. Our AstroYeast has the future potential to increase their nutrient yield in space.

In the third phase of our Real Time Technology Assessment, Public Perception, we explored how synthetic biology solutions for food production in space were perceived. It was clear that the public sees these initiatives as exciting endeavours to further technology and innovation, not only for space travel, but with positive implications here on Earth, with 84% of Canadians supporting our space agency (6). Technological innovations in space can help the human race on Earth. The Canadian Space Agency exemplifies this space-Earth application connection as they have began a space nutrients initiative coupled with food systems for harsh environments. They believe that by linking these two research initiatives they will discover solutions faster to feeding astronauts and people in food deserts.

With respect to our project, AstroYeast, which are space-compatible chassis for bioproduction of nutrients, could also be used for other applications here on Earth. Scot Bryson had suggested that our resistant strains may develop phenotypes, such as resilient cell walls, which could be beneficial for fermentation applications here on Earth (3). In addition, insights gained throughout the research process could contribute to foundational yeast research as we discover how the microgravity conditions are impacting the cell. This is informed speculation at this point and we are excited to explore these avenues when our project reaches this milestone.

Public Perception also highlighted how much the space agencies command the media outlets (6). They release most of their own press which is tailored to educational content or to innovation and technology initiatives. With respect to space food technologies we see that public perception of synthetic biology is entwined. The skepticism of bioengineered foods is nestled next to critiques of spending Earth's resources to travel to space, when we could be tackling challenges here on Earth. Nonetheless, the space agencies have successfully woven a narrative of technology, innovation and progress in space with direct benefits to Earth. Space research is widely supported and "synthetic biology is being portrayed as an emerging discipline with untapped potential (6)."

The importance of connecting space studies with Earth applications is highlighted by Morgan Irons of Deep Space Ecology agricultural solutions for Earth and Mars,

> **" I've come to realize how important it is that we also have that Earth track as well, as how space can feed back into the Earth industries and solve problems here on Earth (4)."**

The clarification of Earth applications for AstroYeast will strengthen our project's impact and implementation from the point of public perception.

We explored the ethical, legal and social implications of AstroYeast throughout the Real Time Technology Assessment. The process has highlighted projects similar to ours, current practice in space food technologies and public perception of these technologies. We have gained valuable insight throughout this process which has influenced our technological choices for AstroYeast, a space-compatible chassis for the bioproduction of nutrients in space. We were made aware of how young the field of bioproduction is and how little the public is aware of this field. Likewise innovations in space food technologies are young as we have just breached space habitation.

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Connecting with the small community of burgeoning synthetic biologists in microgravity research and space food technologies will be essential to the success of our project. Therein lies a current of untapped potential, an ability to contribute to space exploration but also to Earth applications. The youth of these fields allows for a current of optimism in public perceptions, which we can be harnessed to further our project through outreach, education and, once we create our AstroYeast, implementation. We are excited to continue this evaluation of our design as we progress. We are optimistic and eager to learn from others, to consider the public, the environment and to be informed as we design responsibly.

References:

1. Baxter, B., Nguyen, N. H., & Vlassopolous, L. (2020). Analogical Case Study (Essay, Concordia University, 2020). Montreal, QC: IGEM.

2. IGEM Concordia in Dialogue with Dr. Corey Nislow [Interview by iGEM Concordia]. (2020, July).

3. IGEM Concordia in Dialogue with Scot Bryson [Interview by iGEM Concordia]. (2020, August).

4. IGEM Concordia in Dialogue with Morgan Irons [Interview by iGEM Concordia]. (2020, July).

5. Karuppayil, S. M., & Halbandge, S. D. (2017). Saccharomyces cerevisiae as a Model for Space Biology. In 941744929 735858963 T. Satyanarayana & 941744930 735858963 G. Kunze (Authors), Yeast Diversity in Human Welfare(pp. 29-52). Singapore: Springer. Doi:10.1007/978-981-10-2621-8_2

6. O'lano, G. (2020). Public Perception (Essay, Concordia University, 2020). Montreal, QC: IGEM.

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