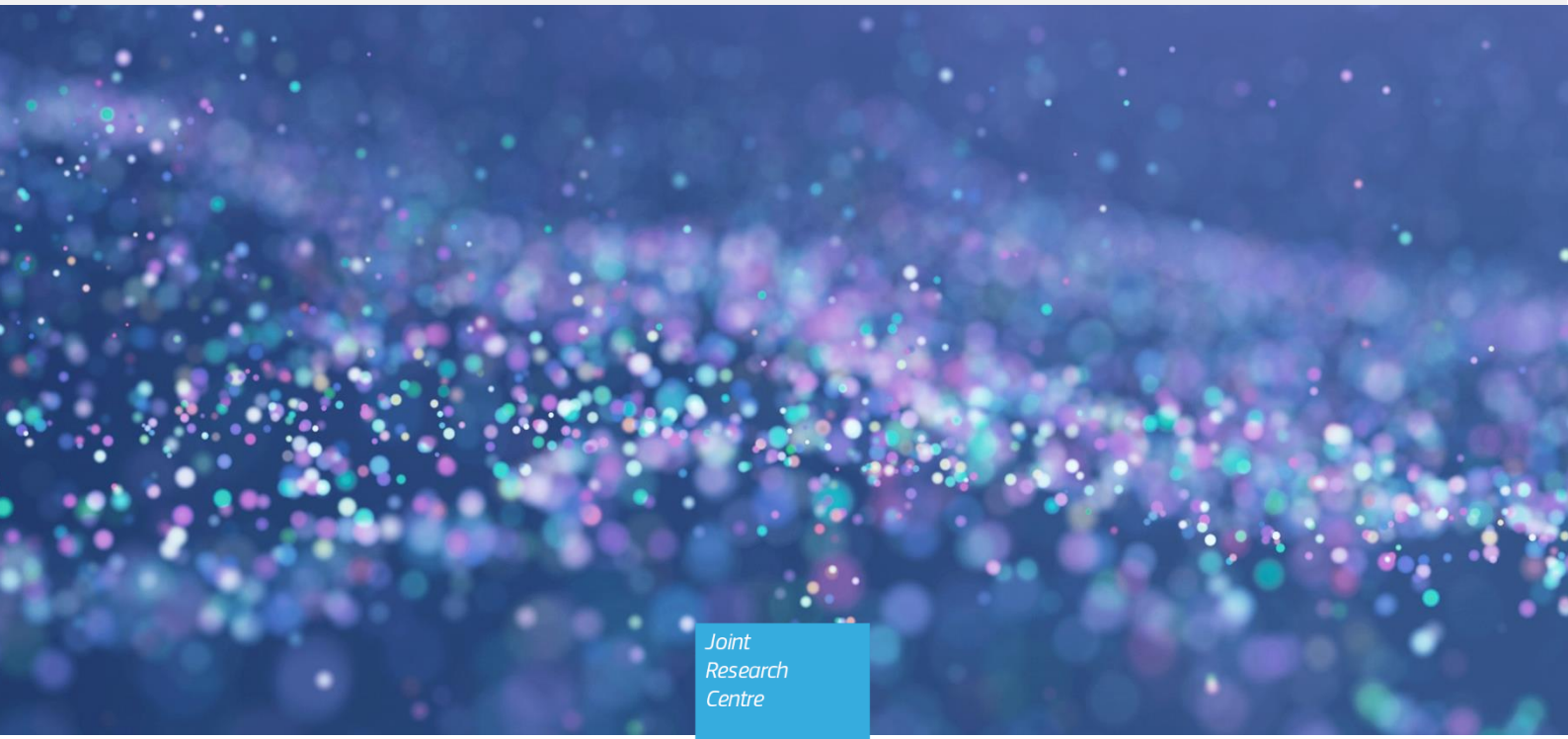
European Commission

JRC Makers-in-Residence Programme

Arctic's Plastics

Léon Reboul

2024



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Contents

Abstract

This report describes the work carried out during the Maker-in-Residency programme of the European Commission's Joint Research Center (JRC), in Ispra (Italy). The goal of the project was to design and produce an open-source board game around the topic of co-creation of knowledge on Arctic's plastic. The board game was manufactured using the equipment available at the JRC Makerspace, in particular a laser cutter. The aim of the board game is to raise awareness about the problematic of (micro) plastic pollution in the Arctic. Plastic waste from all over the world can be transported to the Arctic by ocean currents. This means that even regions far from the Arctic contribute to its pollution. The Arctic Ocean acts as a sink for marine debris, accumulating plastics from both local and distant sources. The source files of board game are shared to allow other Fab Labs/Makerspaces to make their own copy for educational (non-commercial) use.

Figure 1: Arctic's Plastics the board game, first prototype made with the JRC Makerspace laser cutter, with a modular map, modular personal boards for red player (research vessel and land-based Lab) and meeples with first rules for the games. Source: Léon Reboul.

Acknowledgements

First, I would like to thank Paulo Rosa and Ângela Guimarães Pereira for making this residency possible and for their direct implication and feedback in this project!

I would like to thank Ilaria Crotti for the time she gave me during a discussion on Arctic pollution and for giving me the contact of a terrain researcher.

I would like to thank Francesca Battaglia for taking the time to answer question on the life of a researcher in a research vessel.

I would like to thank Alexandre Rousselet from the Vulca programme (https://vulca.eu/) for connecting me with Fab Labs and Makerspace all around Europe.

Author

Léon Reboul

I am a French engineer; I did Fab Academy (a distributed formation from MIT professor Neil Gershenfeld on digital fabrication) in 2020 and worked as a Fab Manager for 2 years in a French Fab lab in Mulhouse.

With Alexandre Rousselet from Vulca NGO I am visiting Fab Labs and Makerspaces in Europe.

I did a 3-month exchange at FabLab Skanderborg, Denmark, with MakerTour in 2023. I am involved in the French FabLab network, I am one of the leaders of the working group "Game, Arts and culture".

I am creating a moving game Lab: the “Arctic Tern Game Lab” a small Fab Lab on a cargo bike with a trailer that is centred on board games, video games and escape rooms/boxes.

Figure 2: First prototype for the laser box for the Arctic Tern Game Lab. Source: Léon Reboul.

Figure 3: The “last kilometre delivery system” I plan to use for my moving game Lab: an electric cargo bike and a modular bicycle trailer from Bicylift. Source: Léon Reboul.

1 Introduction

1.1 Context

The work was conducted at the European Commission's Joint Research Centre (JRC), during a makers-in-residence programme organised by the JRC Makerspace, in February 2024. The physical production of the board game was done using the equipment available at the JRC Makerspace, in particular using a laser cutter.

Why make an open-source board game on plastic pollution in the Arctic?

As stated in Romero Manrique, Zoghbi, and Guimarães Pereira (2021), "*Climate change is leading to detrimental impacts on the Arctic and indigenous people* [...] *Changes due to a warming Arctic affect the global population and will have a lasting impact on our common ability to survive. Indigenous people hold valuable knowledge and skills that could deliver early-warning signs through their experiential and traditional knowledge*"

Furthermore, as pointed out by Bergmann et al., (2022):

- "*Plastic pollution is now pervasive in the Arctic, even in areas with no apparent human activity, such as the deep seafloor.*"
- "*It has infiltrated terrestrial and aquatic systems, the cryosphere and the atmosphere.*"
- "*It has become a concern for animal and human health.*"
- "*It is linked to climate change.*"

Plastic pollution in the Arctic region is particularly problematic for several reasons:

1. **Remote and Fragile Ecosystem**: The Arctic is a remote and fragile ecosystem, home to a diverse range of wildlife, including polar bears, seals, whales, and seabirds. These species are highly adapted to their environment, but plastic pollution disrupts their habitat and food sources, leading to severe ecological consequences.

2. **Cold Climate and Slow Degradation**: The cold climate of the Arctic slows down the degradation process of plastics. Unlike in warmer regions, where sunlight and higher temperatures can help break down plastic, in the Arctic, plastic can persist for much longer periods, leading to a buildup of pollution.

3. **Transport by Ocean Currents**: Plastic waste from all over the world can be transported to the Arctic by ocean currents. This means that even regions far from the Arctic contribute to its pollution. The Arctic Ocean acts as a sink for marine debris, accumulating plastics from both local and distant sources.

4. **Impact on Marine Life**: Marine animals often ingest plastic debris, mistaking it for food. This can lead to physical harm, blockages in the digestive system, and exposure to toxic substances. Additionally, plastic debris can entangle marine animals, causing injury or death.

5. **Chemical Pollution**: Plastics can absorb and concentrate toxic chemicals from the surrounding water. When marine animals ingest plastics, these toxic substances can enter the food chain, potentially affecting not only wildlife but also indigenous communities that rely on marine resources for sustenance.

6. **Climate Change Interactions**: The Arctic is already severely impacted by climate change, with rising temperatures leading to melting ice and permafrost. Plastic pollution exacerbates these issues. For example, microplastics can influence the melting of sea ice by absorbing heat and contributing to the albedo effect, where the surface reflects less sunlight.

7. **Scientific and Tourism Activity**: Increased human activity in the Arctic for scientific research and tourism also contributes to plastic pollution. These activities can introduce additional waste into the environment, further stressing the ecosystem.

8. **Difficult Clean-up Efforts**: The remote and harsh conditions of the Arctic make cleanup efforts extremely challenging and costly. This means that once plastic pollution enters the Arctic environment, it is difficult to remove, leading to long-term environmental impacts.

The combination of these factors makes plastic pollution a significant threat to the Arctic region, impacting both its unique ecosystems and the global environment. Efforts to reduce plastic pollution globally are essential to protect the Arctic and its inhabitants.

Why make a board game on co-creation of knowledge?

The board game takes inspiration as well from the "Ethical and equitable engagement synthesis report", written by the Inuit Circumpolar council - a collection of Inuit rules, guidelines, protocols, and values for the engagement of the Inuit Communities and Indigenous Knowledge from Across Inuit Nunaat. The synthesis highlights how scientific research was problematic in the Arctic:

- It used to look down on indigenous traditional knowledge,
- It used to exclude Arctic communities from the decision-making process
- It used to exploit Arctic communities' knowledge without retribution to the owners.

1.2 Proposal

The objective of this project was to develop an open-source board game on Arctic's (micro) plastic pollution, with an emphasis on the element of co-creation of knowledge. The board game was named *Arctic's Plastics*. It allows non-technical people to get ecological awareness on Arctic Ocean's pollution, while playing the game.

In the board game *Arctic's Plastics*, the player is placed in the role of a captain of a research vessel that needs to gain knowledge on the status of the plastic pollution in the Arctic region: water, species and land. The game uses a worker placement mechanism - the player uses a crew of researchers and engages with the local Arctic communities to collect samples and analyse them in the player's laboratories, one located in the research vessel and other in a land base.

The board game *Arctic's Plastics* is provided as an open-source board game that can freely be replicated in other FabLabs/Makerspaces worldwide. By manufacturing the board game using equipment and materials commonly available in makerspaces, others can easily replicate the board game and propose it to the public. Wood components were preferred to plastic one, due pollution consideration and the thematic of the board game.

Who can use the game?

- Teachers and Educators
- Environmentalists and Activists
- Museum and Exhibit Curators
- Parents and Families
- Corporate Sustainability Officers
- Researchers and Academics

Educational Settings:

1. Schools (Primary, Secondary, and Higher Education):

    - Teachers can use the board game as an interactive tool to teach students about environmental science, specifically focusing on plastic pollution and its impact on the Arctic ecosystem.

2. Universities and Colleges:

    - Environmental science and studies programs can use the game as a teaching aid or for research purposes.

    - Students studying game design or educational tools could analyse the game for its educational impact and design features.

Organisations:

1. Non-Governmental Organizations (NGOs):

    - NGOs focused on environmental conservation can use the game for outreach and education programs. It can be used in workshops and community events to raise awareness about plastic pollution.

2. Museums and Science Centres:

    - Museums and science centers can include the board game as part of their interactive exhibits on climate change, pollution, and the Arctic.

    - It can serve as a hands-on educational activity for visitors of all ages.

3. Community and Youth Groups (Scout Groups, Clubs, and Youth Organizations and so on):

    - These groups can use the game to educate their members about environmental stewardship and the impact of pollution on different ecosystems.

    - It can be part of their environmental badge programs or community service projects.

4. Libraries (Public and School Libraries):

    - Libraries can include the game in their collections for patrons to borrow and use.

    - They can also host educational events or game nights to raise awareness about plastic pollution.

Families and Individuals:

1. Home Use:

    - Families can play the game together to learn about environmental issues in a fun and engaging way.

    - It can be a tool for parents to teach their children about the importance of protecting the environment.

2. Environmental Activists:

- Activists can use the game as a tool to engage communities and individuals in discussions about plastic pollution and environmental protection.

Corporate and Professional Development

1. Corporate Training Programs

   - Companies focusing on sustainability can use the game in their employee training programs to raise awareness about environmental issues.

   - It can be used in team-building activities to foster a culture of sustainability within the organization.

Overall, the board game about plastic pollution in the Arctic can be a versatile educational tool suitable for a wide range of users and settings, helping to raise awareness and promote action against plastic pollution.

2 Process and implementation

The board game *Arctic's Plastics* was fully developed during the 10-days on-site residency of the Joint Research Centre. However, its conception can be traced back to another board game developed by me. I designed and made a first board game on plastic pollution with a laser cutter in a Fab Lab in Montpellier before the residency at the JRC Makerspace.

The general process for the residency at the JRC Makerspace was the following:

1. Conduct desk-based research on google scholar on the topic of micro-plastic pollution in the Arctic,
2. Select relevant scientific articles to base the board game,
3. Exchange with JRC researchers on the topic of plastic pollution in the Arctic,
4. Desing the various components of the board game, using 3D and 2D computer assisted design (CAD) with Openscad and Inkscape (3D and 2D open-source CAD software),
5. Manufacture the various components (cut and engrave) on wood with the JRC laser cutter,
6. Finalise the components by painting them by hand.

Figure 4: Making tokens for the samples of the arctic animals contaminated by micro plastics with the laser cutter of JRC Makerspace and painting them. Source: Léon Reboul.

Figure 5: Orange player and yellow player personal board: the research vessel and the land-based lab. Source: Léon Reboul.

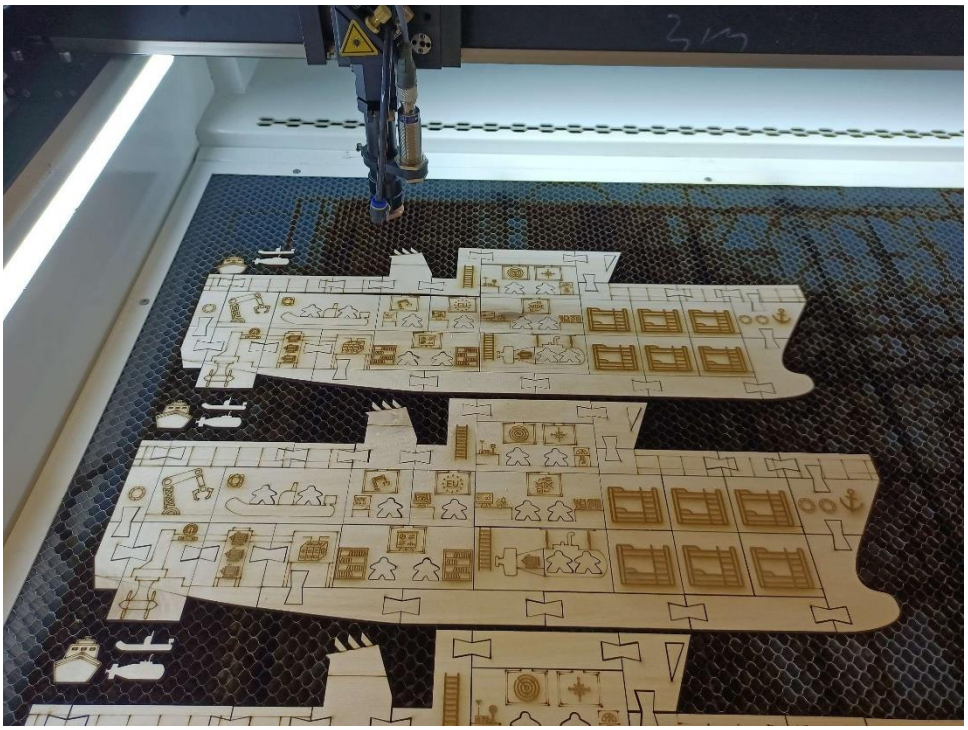
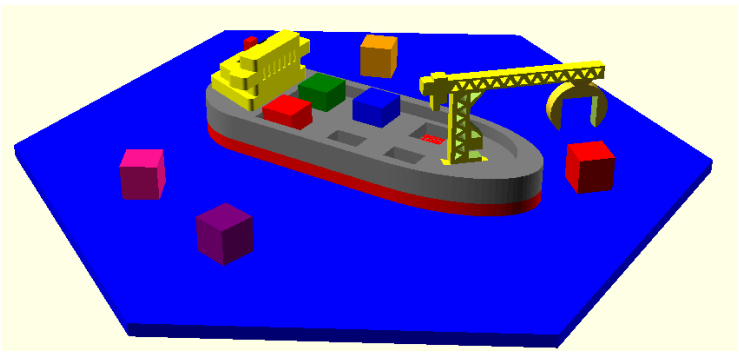


Figure 6: Production of the personal boards for the players with the JRC Makerspace laser cutter. Source: Léon Reboul.



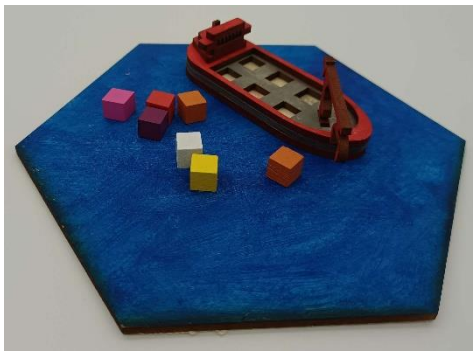


Figure 7: 3D model of a ship collecting plastic trash in the ocean in Openscad. Source: Léon Reboul.

Figure 8: Ship real model, laser cut, glued and painted. Source: Léon Reboul.

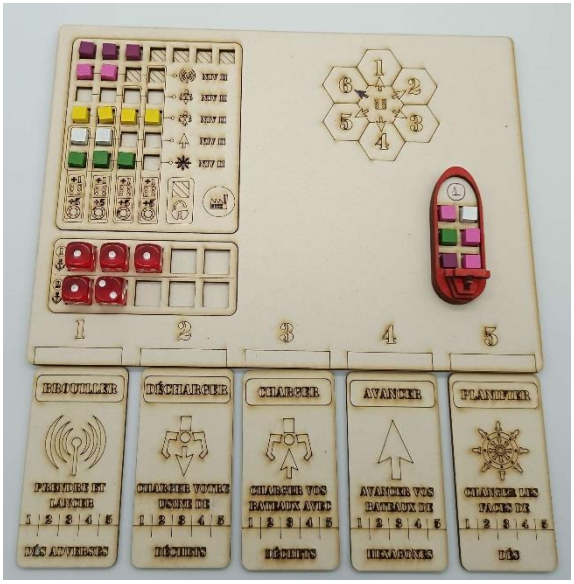


Figure 9: Red player personal board. Source: Léon Reboul.

Figure 10: The game's main board. Source: Léon Reboul.

If you want to make your own version of the board game, please follow the steps and use the files provides in this two Instructables (sharing designs website) I wrote:

https://www.instructables.com/Arctics-Plastics-Board-Game-Prototype-V1/

https://www.instructables.com/Arctic-Clean-Up-Board-Game-Prototype-V1/

3 Prototypes

Two versions of the game were developed:

- Arctic Clean Up: a game centred on micro plastic collection and processing;
- Arctic's plastics: a game on sample collection and gaining knowledge on Arctic pollution.

3.1 First version: Arctic Clean Up board game

The first iteration of the board game took inspiration from the (real world) programme: "The Ocean CleanUp" (https://theoceancleanup.com/). The Ocean Cleanup is a non-profit organization (NPO) that is developing and scaling technologies to rid the world's oceans of plastic.

Goal of the game: In this game you will work with other players to collect pollution tokens from the Arctic Ocean and process them in your factory! You use action card to perform one of the following actions:

- Plan the route of your ship
- Move the ship
- Load pollution token in the ships
- Unload pollution token to your factory
- Analyse water to detect pollution token

Figure 11: Arctic Clean Up board game in display at JRC Makerspace. Source: Léon Reboul.

You can learn to play this game with the rule book available in the Annex section. Please note that it is a prototype, and rules will be subject to change in a near future for better balance of the game.

3.2 Second version: Arctic's Plastics board game

The second version of the board game, entitled *Arctic's Plastics*, instead of using action cards, uses workers in the form of meeple tokens of different colours. Each worker - crew member, hunters, laboratory researchers, community researchers, captain - can perform special actions on your personal board and the main board ().

Goal of the game: In this game you will use your team of researchers and collaborate with indigenous peoples to collect samples of the Arctic animal and water to gain knowledge on micro plastic pollution level and distribution. For example, you can use your researchers to collect samples:

- from ice, using a fast boat with a glacier specialist onboard, on an ice water tile,
- from the sea water column, using a submarine with an oceanographer on a deep-water tile
- from animals, by collaborating with indigenous people. In this case, samples can be collected from:
    - polar bear,
    - arctic fox,
    - seal,
    - ...

Figure 12: The map of this game is modular, allowing the players to test different scenario. Source: Léon Reboul.

4 Reflections

4.1 Main challenges

4.1.1 Design challenge

The main design challenge I faced was to design a board game on a science topic that is both educational and entertaining. For the following reasons:

1. The balance between education and fun: this is the most challenging part: I had to find the right balance between diffusing knowledge and ensuring that the gameplay remains enjoyable: if the game becomes too focused on the educational aspect, it might feel more like a lesson than a game. This feeling could deter player from engaging with the game.
2. Accessibility: I had to make the game accessible to players with low level/no level of scientific knowledge. I wanted the game to be engaging for both those who are advanced on this topic and those who are just starting to learn about it. This was also though design choices as you don't want to overwhelm players with too much information, nor do you want to make the game too simplistic.
3. Theme integration: I chose the theme of the game on purpose to match the science topic behind it. The science topic (Arctic's plastic pollution) then looks to integrate seamlessly into the theme of the game: a science campaign on a research vessel in the Arctic. That was important to me because if the theme feels disconnected from the scientific concepts being taught, the players might struggle to understand the relevance of the information presented.
4. Game mechanics: I had to design engaging game mechanics that reinforce the scientific concepts being taught while also providing room for strategic choices and enjoyment for the players. Another difficulty is that the mechanics has to align with the theme and help reinforce the learning objectives without feeling forced or artificial.
5. Replayability: I make sure that the game has a lot of replay value. This is a key factor for the player to engage in multiple plays of the game: the playthroughs must offer something new and exciting for each game played.
6. Testing and refinement: like all games it needs extensive testing and refinement to ensure that it achieves the desired balance of education and entertainment. Gathering feedback from playtesters and making iteration on the game design was challenging as the JRC access is restricted to the public and the length of the residency was 10 days. Commercial board games usually follow a one-year trial and error refinement process with hundreds of playtesters involved.

4.1.2 Production challenge

The biggest challenge I had during the production phase was in finalising the components. As I painted all the components of the game by hand, this ended up being a very time-consuming process, taking several days.

4.2 What could be done next

4.2.1 Improvements

- I think a good improvement is to either use pre painted wood sheets before the laser cutting or to involve a group from the community of the Fab Lab in making/painting the game. The second option is in my sense better as it allows the community to personalize the board game, making them more involved.
- I am modifying the file to be able to produce the board game on my smaller laser cutter in my mobile game Lab.

Figure 13: Using Xtool "S1" laser cutter to produce the game token and hexagonal tiles. Source: Léon Reboul.

- I started working on a way to sort and store the hexagonal tiles and tokens using folded paper boxes: Japanese origami box called a "masu" box. This will allow fab labs to use paper instead of traditional plastics inserts.
- I plan to do more testing and balancing of the game in board games events and festivals
- The next step is creating extensions for the games and supporting modding of the game by the community of the Fab Lab.

Figure 14: Using origami boxes (paper folded) instead of plastic for storage of the game components. Source: Léon Reboul.

5 Conclusions

During this residency I had the chance to develop a new board game focused on the Arctic's (micro) plastic pollution, using the equipment (laser cutter) and material available at the JRC Makerspace in Ispra (Italy).

I am pleased to have overcome the following design challenges for my game:

1. Balance between education and fun: I made a game that is fun to play: you embark on an exciting journey where you manage your crew and run a science campaign in the Arctic on your research vessel. By playing the game you gather knowledge with samples of Arctic's biome and gain awareness that plastic and microplastic pollution is everywhere from the sea water, the snow to the animals.
2. Accessibility: by making the workers action follow simple rules I made the scientific knowledge level entry to play the game low. You still need to be able to read and count to play the game, but you don't need a PhD in glacier science to play it.
3. Theme integration: I choose on purpose to adapt the theme to the scientific content I wanted to teach. The science campaign in the arctic works well with the knowledge I want to transfer to the players.
4. Game mechanics: the worker specialization in the game is based on real researchers' jobs, I will allow complete neophyte to discover this careers paths and for young people to get interested in them. It also works well with the theme as real research vessel have different experts on board to study various science field during the campaign.
5. Replayability: the map of the game is modular, allowing to play the game in a campaign mode, using several scenarios. The player can create their own map! The research vessel and the land lab rooms are also modular, allowing the player to create their own rooms!
6. Testing and refinement: I had the chance to exchange and gain feedback from Paulo Rosa and Ângela Guimarães Pereira during the weeks of the residency. I also had other great ideas from the meeting with Ilaria Crotti and Francesca Battaglia who too, took the time to answer to questions on the life of a researcher in a research vessel. And finally, I presented the game to the rest of the JRC Makerspace team on the last day of the residency for more feedback on the game's look and on ideas for further improvements.

The prototype of this game is fully replicable in another Fab Labs/Makerspaces. I hope that:

- the game open-source nature will allow other people to create their own expansions/version,
- that when playing the game, the people will be interested in learning more on the plastic pollution level in the Arctic,
- that they will act on their level to reduce their plastic production from their home,
- that this game will help promote the protection of the beautiful but endangered Arctic's spaces and communities.

6 References

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List of figures

Annexes

- Arctic CleanUp rule book V1
- Arctic's Plastics rules book V1

Arctic CleanUp rule book V1

1. Inspiration

The goal of this game is to raise public awareness on plastic pollution in the Arctic. This game took inspiration from the (real world) program: The Ocean CleanUp but also from research papers on Arctic pollution. The Ocean Cleanup is a non-profit organization (NPO). They are developing and scaling technologies to rid the world's oceans of plastic.

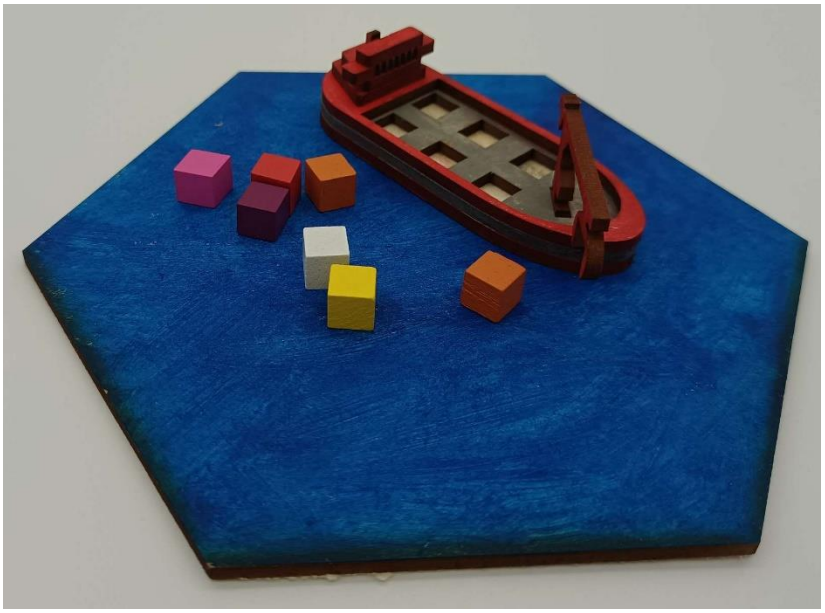

Figure A1: Ship and pollutions tokens Source: Léon Reboul.

Figure A2: Multi players illustration Source: Léon Reboul.

2. Components

2.1 Pollution tokens

50 Pollutions tokens (coloured wooden tokens as shown in Figure 4):

- Red tokens: HDPE, 2 victory points (VP),
- Green tokens: LDPE, 2 VP,
- Blue tokens: EVA, 2VP,
- Yellow tokens: PP, 3VP,
- Grey tokens: PS, 3VP,
- Black tokens: PMMA, 2VP,
- Purple tokens: PET, 2VP,
- Pink tokens: PA6, 2VP,

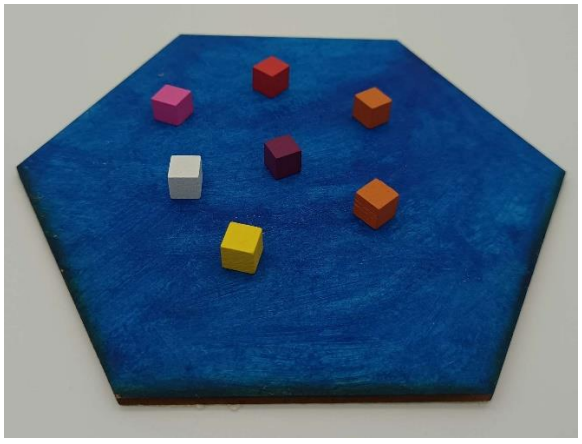

Figure A3: Set of pollutions tokens on a water hexagon Source: Léon Reboul.

2.2 Main board

- 1 main board Ocean (Figure 5)

Figure A4: Main board: the Ocean Source: Léon Reboul.

2.3 Players components

2.3.1 Your fleet

Figure A5: Red player 2 ships and 2 token ships Source: Léon Reboul.

- 2 ships,
- 2 ships tokens.

The ships go on the personal board and the ship tokens go on the main board, they are a representation of your ship on the board. Figure 6 shows the ships and the ships tokens for red player.

2.3.2 Your personal board

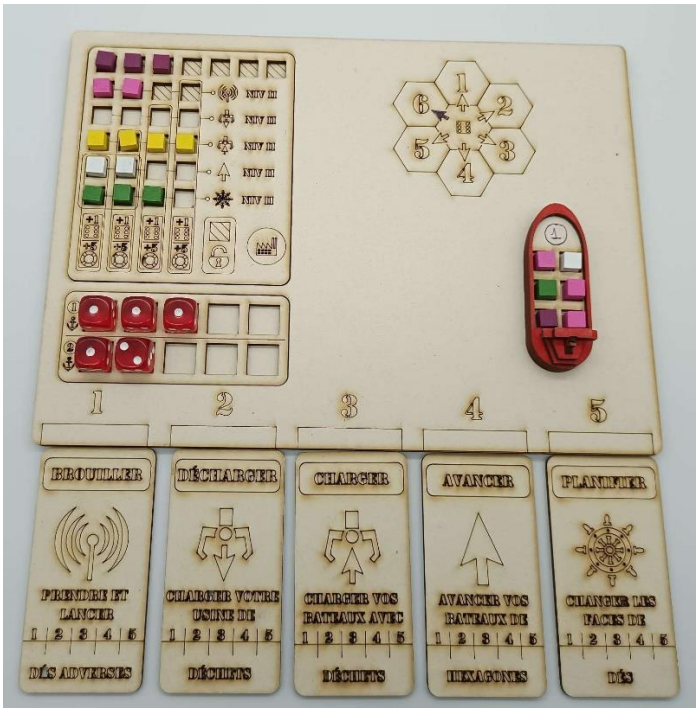

Figure A6: Red player personal board Source: Léon Reboul.

- personal board layout:
    - top left: the factory, where the pollution tokens will be processed (cf. figure 8),
    - top right: a wind rose to help you plan your moves (cf. figure 7),
    - bottom left: your planning zone with dices, (cf figure 7),
    - bottom right: the place you put your 2 ships (cf figure 7),
    - bottom: 5 action cards you will choose one action to do at your turn in this list (cf. figure 7):
        - plan,
        - move,
        - load,
        - unload,
        - analyse.

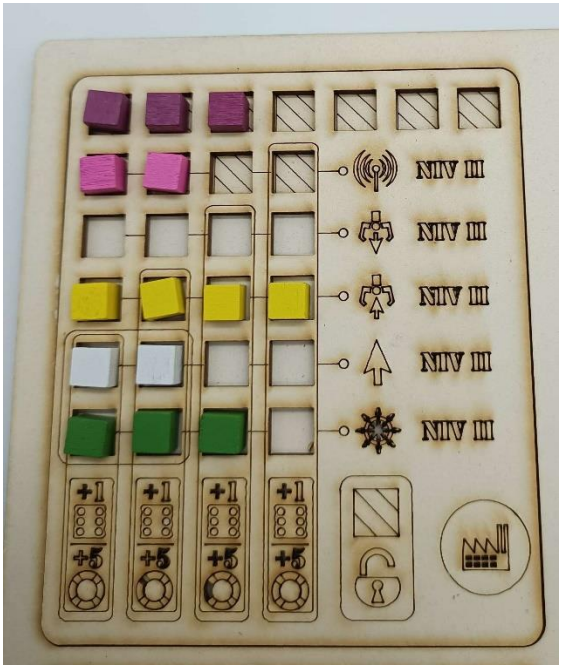

Figure A7: Zoom on red player factory Source: Léon Reboul.

3. Setup of the game

3.1 Global set up

1. Ocean tiles: put the ocean tiles in the hexagonal grid except for the player factories hexagons, refer to the schematics for player factory placement (it changes depending on the number of players).
2. Pollution phase (pollution tokens distribution): this phase represents the past and current generations throwing plastic garbage in the ocean:
    a. take turn to throw cubes from the bag (without looking in the bag) at random locations on the board,
    b. then group the pollution cubes on the ocean tiles so that there is 3 pollutions tokens on each hexagon (ocean tile). No cubes should be on the empty hexagons.
3. Determine players order (random),

4. The last player puts its factory first and so on until the first player puts its factory on the remaining empty hexagon on the board.

3.2 Personal board

- Put the 2 ships and the dices of your colour on your personal board.
- Put only 5 dices on the planning board:
    - 3 dices for the ship 1,
    - 2 dices for the ship 2,
    - all 5 dices should have the face 1 (number 1) up.
- The five other dices remain in the supplies you can use them at the beginning of the game but we will see later how you can gain them!

4 Game play

In Arctic CleanUp players take turns in clockwise order starting from the first player until the end of the game is triggered. When the end of the game is triggered by a player the game end immediately. When it is your turn, you take (only) one action among this list:

- plan the movement of your ships,
- move the ships,
- analyse water to find more pollution tokens,
- load pollution tokens to your ships,
- unload pollution token from your ships to your factory, then it is the next player turn!

4.1 Strength of a card and slide movement

4.1.1 Cards layout

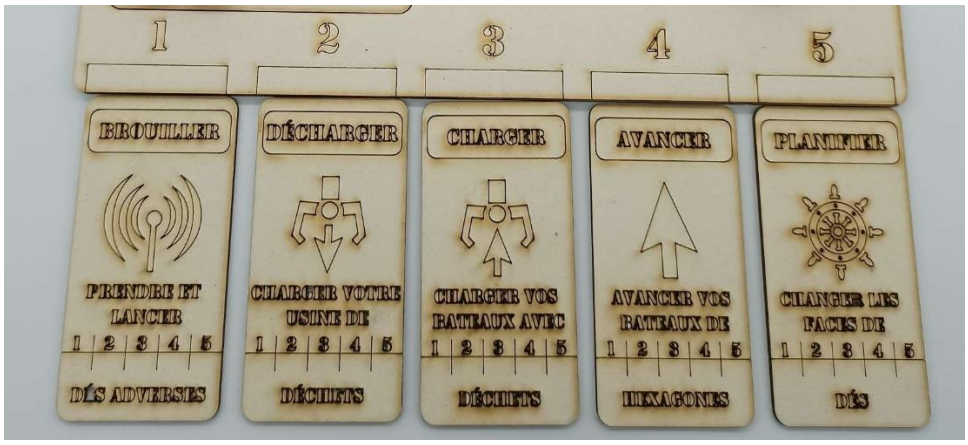

Figure A8: zoom on the action card columns on a personal board Source: Léon Reboul.

The 5 possibles action cards are stacked in columns, from column 1 to column 5 on your personal board as shown in figure 8.

4.1.2 Action mechanism

When it is your turn, you have to:

1. choose only one card action,
2. do the action with the strength X, where X is the number of the column,
3. take the card out, slide all the cards in the columns under it up one column,
4. move the card you used back to column 1.

Important note: when playing a card with strength X you can choose to use it effect with a lower strength than X. For example, playing a strength 5 move action you can decide to only move your ship of one hexagon.

4.1.3 Examples

It is red player turn and her cards are in the layout of figure 9. First, she must choose one action in this list:

- playing the analyse action at strength 1,
- playing the unload action at strength 2,
- playing the load action at strength 3,
- playing the move action at strength 4,
- playing the plan action at strength 5.

Let assume that she chooses the plan action at strength 5. She will affect 5 dices on her planning board (more details on this in the move section). Then she takes out the plan action card, slide all the cards bellow one column up and put the plan action in column 1.

At the end of her turn her cards layout is:

- plan card in column 1,
- analyse card in column 2,
- unload action in column 3,
- load action in column 4,
- move action in column 5.

The sections bellow will explain in more details each action card.

4.2 Plan Action

Figure A9: Zoom on the plan card Source: Léon Reboul.

4.2.1 Planning zone

Figure A10: Zoom on red player planning zone Source: Léon Reboul.

The planning board as two rows as shown in figure 11:

1. the first row is used to plan the move of your first ship token on the main board (ocean),
2. the second row is used to plan the move of your second ship token on the main board (ocean).

4.2.2 Plan mechanism

Use your plan action at strength X to rotate and move X dices on your planning zone:

- rotate the dices to change their upper face values,
- move the dices:
    - from the outside of your personal board to the planning zone:

- Used dices during a move action are removed from your planning board and put on the side of your personal board.
- You can also gain new dices as we will see in the unload action section!
- from one row to another if you want to have more movement for a specific ship.

The rose wind (cf figure 7) help you plan the moves of the ship, if you use a dice with upper face value of:

- 1 your ship will go up
- 2 your ship will go up right
- 3 your ship will go down right
- 4 your ship will go down
- 5 your ship will go down left
- 6 your ship will go up left

4.2.3 Example

After using the plan card at strength 1 you can affect 1 dice by either:

- putting a dice back in the planning board:
  - on row 1,
  - on row 2,
- move one dice from a row to the other row,
- rotate the dice to change the value of its upper face.

Figure 11 shows the result of using action plan at strength 1 where the second dice on the ship 2 row is rotated from 1 to 2.

4.3 Move action

Figure A11: Zoom on the move action card Source: Léon Reboul.

4.3.1 Move the ships

Use your move action with strength X to remove X dices from your planning

board and move X times your ships tokens on the main board.

4.3.2 Example

Let assume we have figure 11 layout of dices and that you can and choose to do

a strength 5 move action. You could do the following:

1. remove the 3 dices from row 1 and then move ship 1 token on the main board 3 times up,
2. remove two dices from row 2 and then move ship 2 token on the main board up and then left up.

But you could also choose to play the card with a lower strength then 5: for example, only move ship 1 one time up and remove 1 dice on row 1 but do not move ship 2.

4.4 Load action

Figure A12: Zoom on the load action card Source: Léon Reboul.

Use the load card with strength X (1 to 5) to load up to X pollution tokens on your ships.

4.4.1 Process

- Take the tokens from the main board and put it in the corresponding ship on your personal board.
- You can split the number of tokens to load as you want between your two ships.
- You can load all type of pollution tokens in your ship, but the pollution tokens that score 3VP tokens at the end of the game requires a special bonuses unlock in your factory to unload them on special processing lines!

4.4.2 Requirement

To load a pollution token, it must be on the same ocean tile as your ship.

4.4.3 Restrictions

Be careful:

- you cannot load tokens on a ship that is already full!
- you cannot throw back pollution token from your ship to the sea (that would be polluting)!
    - you cannot exchange a token from your ship to a better one from the sea if your ship is already full.
    - You can only get rid of the loaded token by unloading them in your factory, if possible (more on that on the next section).
    - you cannot load your 2 ships full of 3VP pollution tokens before you have unlocked the corresponding block bonus. You need to have at least one free space to load regular 2 VP otherwise you will be locked with two full ships and no way of unloading them...

4.4.4 End game scoring

Loaded token that are remaining in your ships at the end of the game only give you 1 victory point regardless of their type (instead of 2VP or 3VP in the factory)!

4.4.5 Example

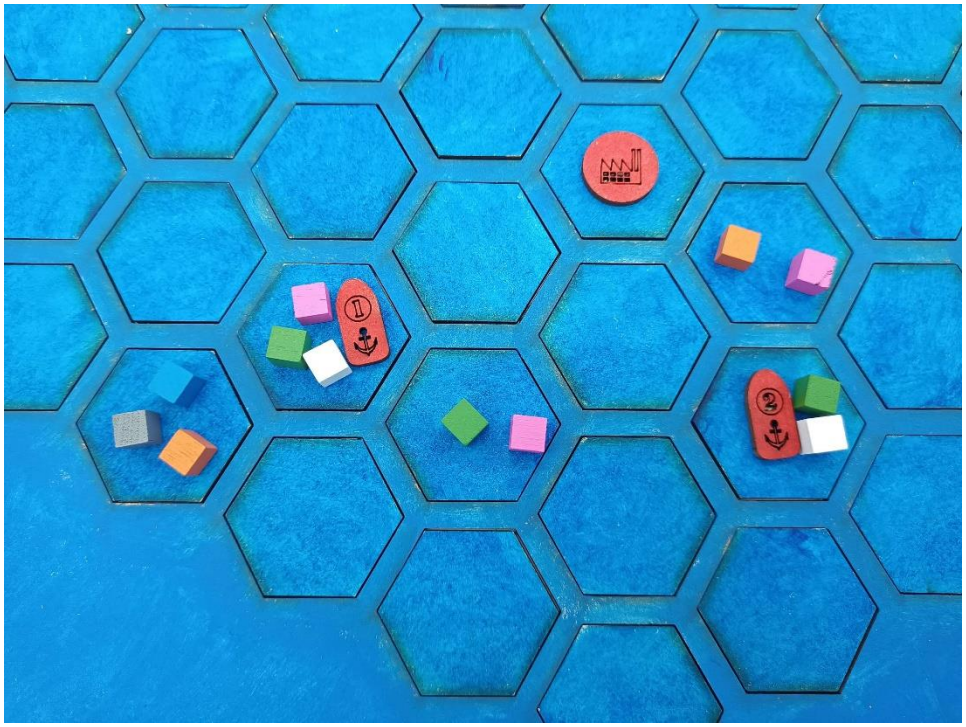

Figure A13: Loading tokens on your ships Source: Léon Reboul.

Let assume we have figure 13 scenario, and that you can use a load action with strength 5. You can load the 3 tokens on the same ocean tile that ship 1 and the 2 pollutions tokens that are on the same ocean tile that ship 2. Figure 14 shows the tokens in the corresponding red player's ships.

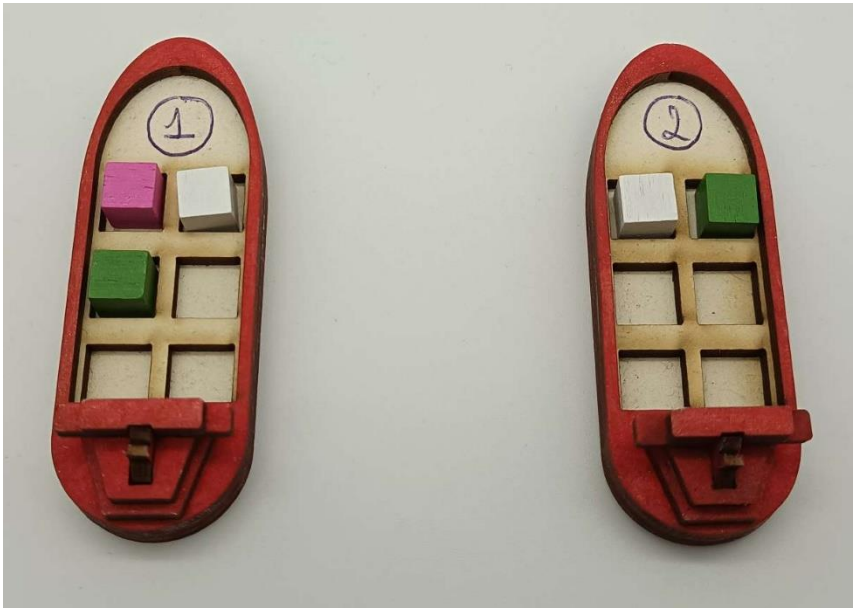

Figure A14: Loaded tokens on red player ships Source: Léon Reboul.

4.5 Analyse water to find more pollution token

Use the Analyse card with strength X to take X pollution tokens from the pollution tokens bag (without looking in the bag) and put them on the tiles where your ships are.

You can choose the distribution of pollution tokens between your two ships.

4.6 Unload action

Figure A15: Zoom on the unload action card Source: Léon Reboul.

Use the unload card with strength X (from 1 to 5) to unload X pollution token in your base factory.

4.6.1 Requirements

Your ship must be on an ocean tile touching your factory to unload. Figure 16 shows a configuration where red player's ship 1 can unload but ship 2 cannot.

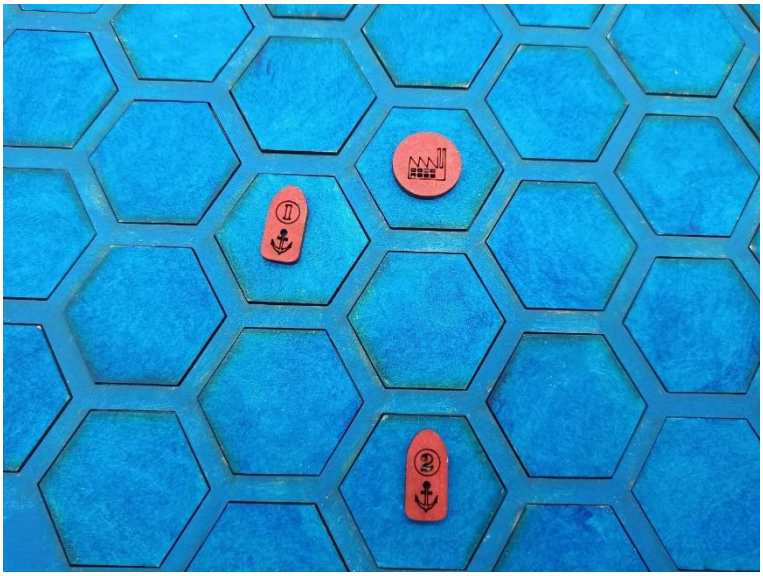

Figure A16: Zoom on the unload action card Source: Léon Reboul.

4.6.2 Pollution tokens in the factory

Put every token of the same colour on the same line of your factory, always start the line from the left, you can't store 2VP tokens on the hatched lines those are in construction for processing only 3VP pollution tokens!

you can't mix pollution token type (colour) on a same factory line, once you start with a colour you need to commit to it and ll the line with the same colour (be strategic when loading the pollution cubes!).

You can have multiple lines of the same colour. Pollution token processed on any player factory is public information for other players.

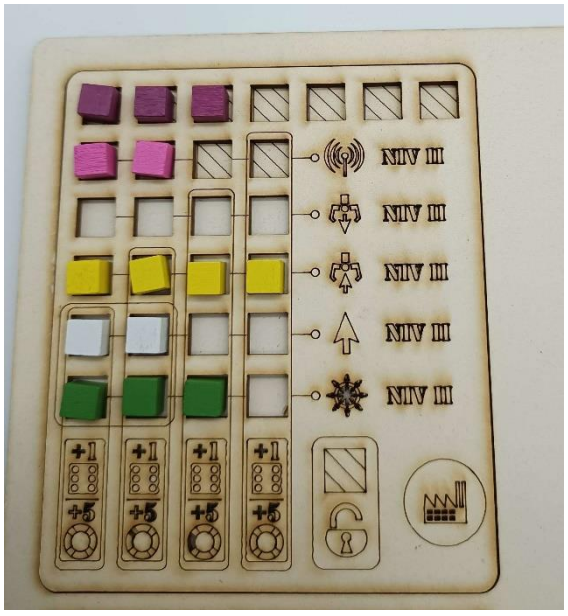

Figure A17: Zoom on the factory of red player Source: Léon Reboul.

4.6.3 Gaining dice block upgrades

After filling a block with pollutions token that is attached to a dice reward, the player gains a new dice from the supply. It can be used for the rest of the play. The player also gets a 5VP bonus for each dice upgrade at the end of the game. Figure 18 shows a factory where the player unlocked the rst dice block Bonus.

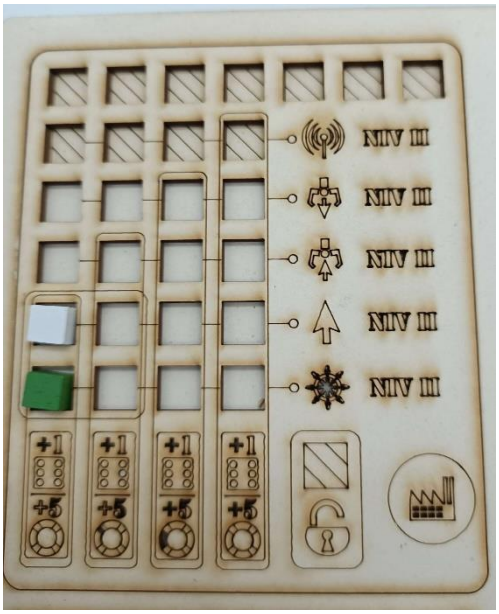

Figure A18: Zoom on the factory of red player Source: Léon Reboul.

4.6.4 Gaining access to the 3VP pollution tokens hatched processing lines

You need to have 2 tokens on the bottom processing line and two tokens on the processing line above to unlock this bonus!

Congratulations!

- You can now unload 3VP pollution tokens in your factory, but only on the hatched processing lines.
- You will be able to upgrade the Analyse card if you fulfil the hatched processing line with 4 emplacements.
- You cannot put 3VP tokens on the regular processing lines.

As for regular 2VP tokens when you start a hatched processing line with a type of 3VP pollution token (a colour) you can only put the same type on all the line no mixing of the trash.

- Reminder: you cannot put 2VP tokens on the hatched processing lines at any times.

4.6.5 Gaining the analyse upgrade

When you have unlocked the 3VP processing line block, and you have completed the hatched processing line with 4 emplacement line (with 3VP tokens of the same colour) you can upgrade your analyse card by flipping it to the upgraded side!

4.6.6 Gaining the other upgrades

When you have completed the processing line with 4 emplacement line (with 2VP tokens of the same colour) that match the logo of the action you can now upgrade your card by flipping it to the upgraded side!

4.6.7 Benefits of the upgrade

When playing an upgraded card with strength X you can now play the action with the double of X as an effect!

For example, playing an upgraded move action at strength 5 gives you 10 moves that you can allocated to your 2 ships (but you need to unlock additional dice to fully benefit from this upgrade, don't you!).

4.7 End of the game

4.7.1 Triggering

After an unload action if a player has 16 pollution tokens or more in the factory, the game ends immediately! There are no more actions for the other players. So I suggest that you keep an eye on other players factory, their ships cargo and their ships positions during the game!

4.7.2 Scoring points

Count the victory points in your factory:

- points for pollution tokens,
- points for upgrades unlocked.

Count the victory points for remaining pollution tokens in your ship:

- 1 point for every pollution token still onboard of your ship (regardless of the colour).

The player with the most points at the end of the game wins.

In case of a tie, players tied share the victory.

Figure A19: Happy Arctic Ocean cleaning! Source: Léon Reboul.

Arctic's Plastics rules book V1

1 Introduction

The goal of this game is to raise public awareness on co-creation of knowledge on micro plastic pollution in the Arctic involving local communities' knowledge.

This game took inspiration from research papers on Arctic pollution by (micro) plastics.

In this game you will go on a science campaign to collect samples in the Arctic to gain knowledge on plastic distribution in the Arctic flora and fauna. You manage a crew of researchers, a captain and technical staff to collect samples and bring them to your research vessel and land laboratories. Strategically upgrading your workers and collaborating with arctics communities will be key to win this game!

Figure B1: Display of the first prototype of the board game in the JRC Makerspace Source: Léon Reboul.

1. Components

1.1 Main board components

1.1.1 Hexagonal tiles

The main board is composed from hexagonal tiles:

- water tiles,
- deep water tiles,
- shallow water,

- forest tiles,
- snow forest tiles,
- sea ice tiles,
- pack ice tiles,
- mountains tiles,
- hazardous tiles:
    - nuclear power plant tiles,
    - military base tiles,
    - mine tiles,
- Arctic communities' tiles,

Figure B2: Main board of the game with modular boarder and hexagonal tiles. Source: Léon Reboul.

1.1.2 Meeples

- the arctic community meeples: fishers (blue meeples) and hunters (brown meeples).
- the animal meeples: meeples in the shape of a
    - polar bear
    - whale
    - killer whale
    - krill
    - octopus
    - snow fox
    - snow owl
    - reindeer
    - seagull
    - crab
    - Greenland shark
    - Walrus
    - Seal
    - Salmon

Figure B3: Animal meeples. Source: Léon Reboul.

1.1.3 Samples tokens

- water sample from the sea (water tiles) : blue wooden cube,
- water sample from the water column (water tiles): grey wooden cube,
- water sample from the bottom of the ocean (deep water tiles): black wooden cube,
- ice sample (sea ice or mountain tiles): white wooden cube,
- snow sample (ice pack/snow tiles): cyan wooden cube,
- animal sample token: cube shaped with the animal drawing on it.

Figure B4: Animal sample tokens. Source: Léon Reboul.

1.1.4 Knowledge tokens on (micro) plastic pollution

The knowledge tokens represent some of the (micro) plastic that pollute the Arctic, you want to find as many as possible during the game:

- PS: Polystyrene knowledge token, PS is one of the most widely used plastics, with the scale of its production being several million tonnes per year. Polystyrene is naturally transparent but can be coloured with colorants. Uses include protective packaging (such as packing peanuts and in the jewel, cases used for storage of optical discs such as CDs and occasionally DVDs), containers, lids, bottles, trays, tumblers, disposable cutlery, in the making of models, and as an alternative material for phonograph records.

- PP: Polypropylene knowledge token, PP is the second-most widely produced commodity plastic (after polyethylene). Its properties are similar to polyethylene, but it is slightly harder and more heat-resistant,

- PUR: Polyurethane knowledge token, PUR global production in 2019 was 25 million metric tonnes, accounting for about 6% of all polymers produced in that year

- PE: Polyethylene knowledge token, PE is a polymer, primarily used for packaging (plastic bags, plastic films, geomembranes and containers including bottles, etc.). As of 2017, over 100 million tonnes of polyethylene resins are being produced annually, accounting for 34% of the total plastics market.

- PMMA: Polymethyl methacrylate knowledge token, PMMA plastic is often used in sheet form as a lightweight or shatter-resistant alternative to glass

- PVC: Polyvinyl chloride knowledge token, PVC is the world's third-most widely produced synthetic polymer of plastic (after polyethylene and polypropylene). About 40 million tons of PVC are produced each year.

- PA6: Polycaprolactam knowledge token, PA6 is a significant construction material used in many industries, for instance in the automotive industry, aircraft industry, electronic and electro technical industry, clothing industry and medicine. Annual demand for polyamides in Europe amounts to a million tonnes.

- PC: Polycarbonate knowledge token, PC used in engineering are strong, tough materials, and some grades are optically transparent. They are easily worked, molded, and thermoformed. Because of these properties, polycarbonates find many applications,

- PET: Polyethylene terephthalate knowledge token, PET is the most common thermoplastic polymer resin of the polyester family and is used in fibres for clothing, containers for liquids and foods, and thermoforming for manufacturing, and in combination with glass fiber for engineering resins. In 2016, annual production of PET was 56 million tons.

Figure B5: Pollutions tokens. Source: Léon Reboul.

1.2 Players components

1.2.1 Worker Components

In this game you will begin with an uncertified crew that you can upgrade/certify during the game. All possible workers in the game are:

- the captain: the captain can be junior (red meeple)/senior (magenta meeple)/legendary (purple meeple)

- the generic researcher: this your “uncertified level” researcher (wood color meeple) it can be upgraded/certified to a specialized researcher:
    - the glaciologist (white meeple),
    - the snow specialist (cyan meeple),
    - the oceanologist: junior (Grey meeple)/senior (black meeple),
- the technician: the technician can be junior (yellow meeple) or senior (orange meeple),

The upgraded/certified meeples will have better effect when used in the rooms of your research vessel and the rooms of your land lab.

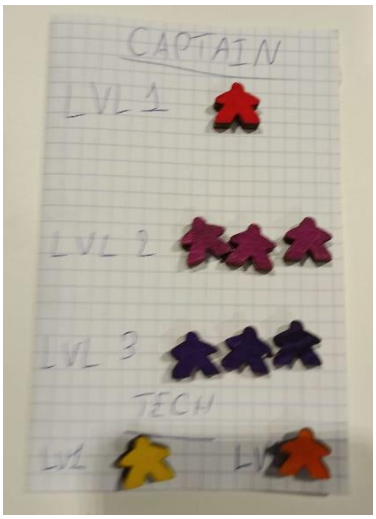

Figure B6: Captain and tech meeples upgrades. Source: Léon Reboul.

1.2.2 Your research vessel

Your research vessel has the following rooms:

- the bridge room: it is where the captain and one technician drive the ship,
- the laboratory room: send a researcher here to analyse samples, this will score you points at the end of the game,
- the publication room: when you have analysed samples and gain information on plastic pollution you can contribute to the research by publishing an article to the community: this will allow you attract a new uncertified researcher to your research vessel or to your land lab,
- the crane control room: use a technician to unload/load the fast boat or the submarine,
- the diving room: use the captain with a researcher to dive with the submarine and collect water samples,
- the dormitories room: the place where all the workers return after the journey. A dormitory can have a maximum of 2 meeples in it.
- the certification room: the place where you can upgrade the workers by making them pass certification to be able to carry better actions,
- the fast boat room: the place in the research vessel where the fast boat is located, the fast boat can accommodate 2 workers, it can be used to collect water, snow, ice and animal samples.

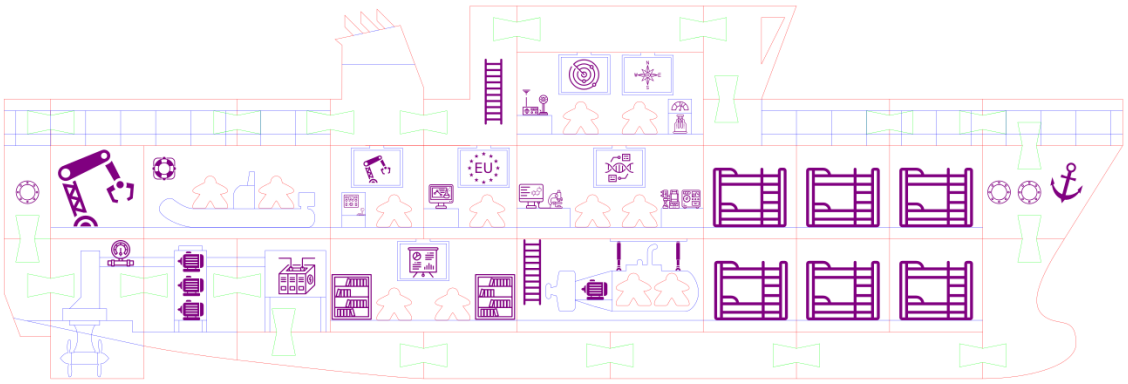

Figure B7: Player board: research vessel Source: Léon Reboul.

1.2.3 Your land lab

Your land-based lab has the following room:

- the dormitories room: the place where the workers return after the journey,
- the study room: the place where you can upgrade the workers!
- the lab room: send a researcher here to analyse samples, this will score you points at the end of the game,
- the snowmobile room: send a researcher here to deploy the snowmobile on snow/ice.

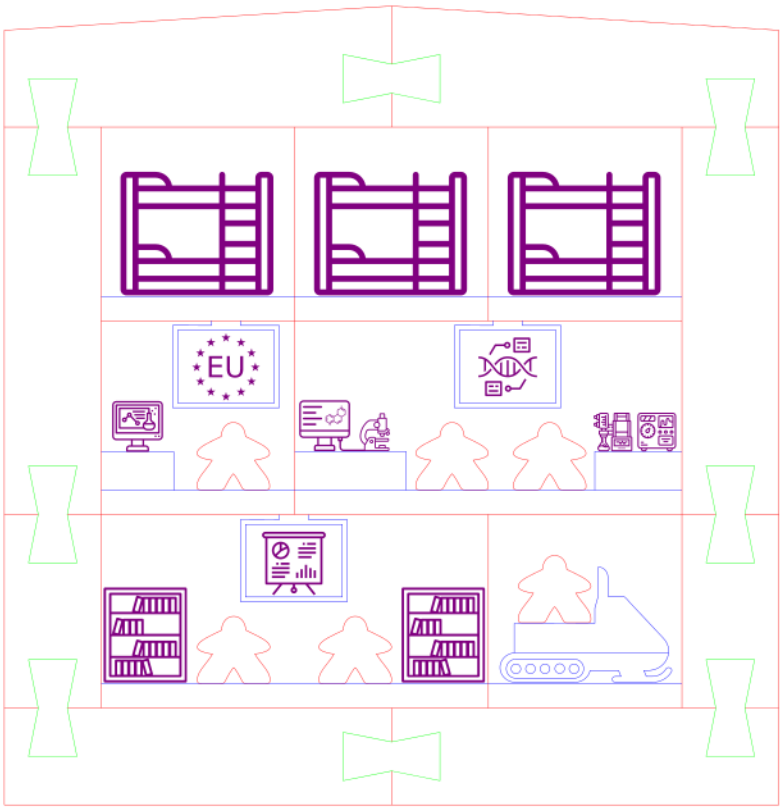

Figure B8: Player board: land Lab. Source: Léon Reboul.

2. Setup of the game

2.1 Global board set up

Set the up the global board according to figure 1

2.2 Personal boards

At the beginning of the game, you have 12 workers: a junior captain, a junior technician and 10 uncertified researchers.

The junior captain and the junior technician must go on your research vessel, place them in a dormitories room. You can them choose to allocate your uncertified researchers to either the land lab or the research vessel, but you can't have more meeple than the number of beds available: 12 beds in the research vessel and 6 beds in the land lab (2 beds per dormitory room).

3 Game play

In Arctic's Plastics players take turns in clockwise order starting from the first player until the end of the game is triggered. When the end of the game is triggered by a player the game end immediately. When it is your turn, you take one action: send 1 or 2 workers from a dormitory room to another room in the research vessel or the land lab. When you don't have any workers left in your dormitories (in the research vessel and the land lab) you pass. When all players have emptied their dormitories a new day start: take all the workers back to the dormitories and start a new day following turn order.

3.1 Rooms and tiles effects depending on the workers specialization

3.1.1 Research vessel

The research vessel token is a representation of the location of your ship on the map. The personal board in the shape of the research vessel represents the inside of your ship, it has the following rooms:

Bridge room:

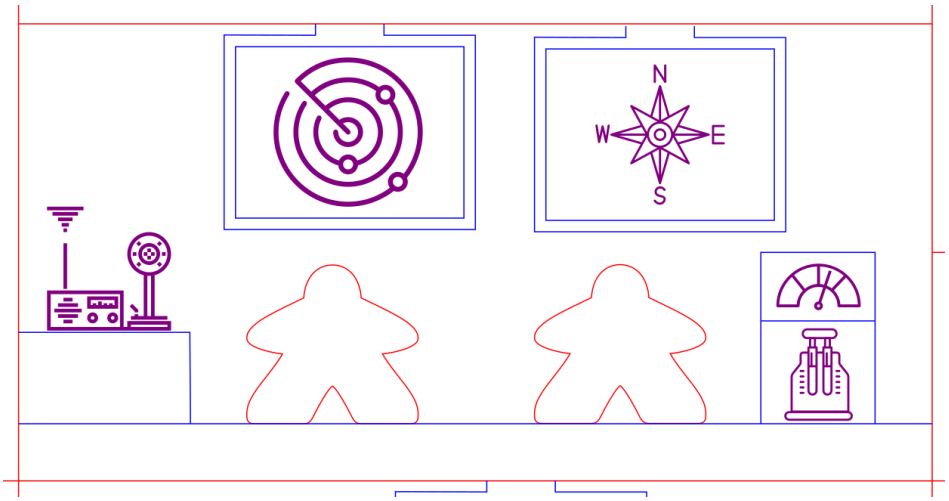

Figure B9: Bridge room. Source: Léon Reboul.

Only the captain and the technicians can go in this room, use:

- a junior captain and a junior technician to move the research vessel 1 tile,

- a junior captain and a senior technician to move the research vessel 2 tiles,
- a senior captain and a junior technician to move the research vessel 3 tiles,
- a senior captain and a senior technician to move the research vessel 4 tiles,
- a legendary captain and a junior technician to move the research vessel 5 tiles,
- a legendary captain and a senior technician to move the research vessel 6 tiles.

Notes:

- your research vessel can only move on the following two tiles: water and deep-water tiles. It can't move on sea ice tiles or land tiles.
- You can't move the research vessel if the captain is diving in the submarine or traveling in the fast boat!
- At any start of a new day, if your land lab and research vessel are on adjacent tiles you can choose to change the distribution of your crew in the research vessel and the land lab, make sure to respects these two rules:
    - the captain and the technicians can't leave the research vessel
    - you must have enough beds for your crew in the research vessel/land laboratory and the ones on a mission in the submarine/fast boat/snowmobile/4x4 (even if they are not back from their trip).

Crane control room:

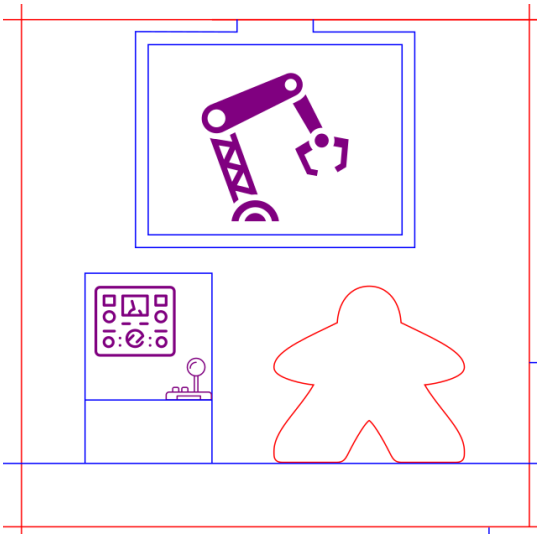

Figure B10: Crane control room. Source: Léon Reboul.

Only technicians can go in this room, use:

- a junior technician to load or unload the fast boat or the submarine, you can't do both during one action, you must choose one)
- senior technician: load or unload the fast boat and the submarine (you can do both at the same action)

Laboratory room:

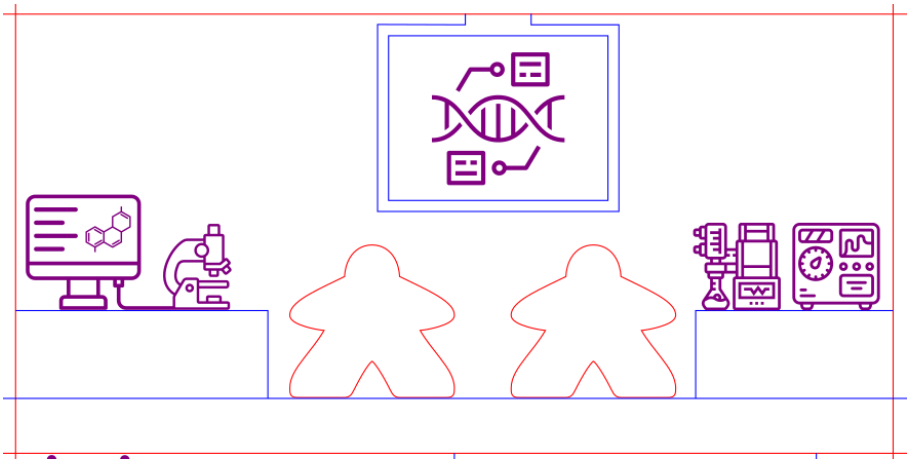

Figure B11: Laboratory room. Source: Léon Reboul.

Only researchers can go in this room, use:

- any researcher (uncertified or specialized) to analyse a water sample from the surface of the sea, (blue wooden cube),
- any researcher (uncertified or specialized) to analyse a sample from an animal, (square wooden cube with a drawing of the animal on it),
- a glaciologist to analyse an ice sample, (white wooden cube),
- a snow specialist to analyse a snow sample (cyan wooden cube),
- a junior oceanographer to analyse a water sample from the water column (grey wooden cube),
- a senior oceanographer to analyse a water sample from the bottom of the ocean (black wooden cube).

When you send a researcher with a sample to the lab try to gain a new knowledge token from the plastic bag:

- draw as many tokens from the bag as you have collected different samples: if you have only one type of sample draw 1 token, if you have 4 different samples draw 4 tokens and so on,
- if it is the first time you do the action for each token you drew from the bag gain a matching token from the supply. Put back the knowledge token that you drew from the bag in the bag.
- if it is not the first time you do an analyse action only keep new knowledge token that you don't have already. If you draw a token, you previously had, that is bad luck, you already have that knowledge, put the token back in the bag and don't gain the token from the supply.

Notes:

- the more sample you have the more probable it is you will gain a new knowledge token,
- if there is no knowledge token matching the one you drew from the bag in the general supply you don't get anything! Too late (and too bad) the other labs have already analysed this, and we don't get new knowledge from your analyses...

Publication room:

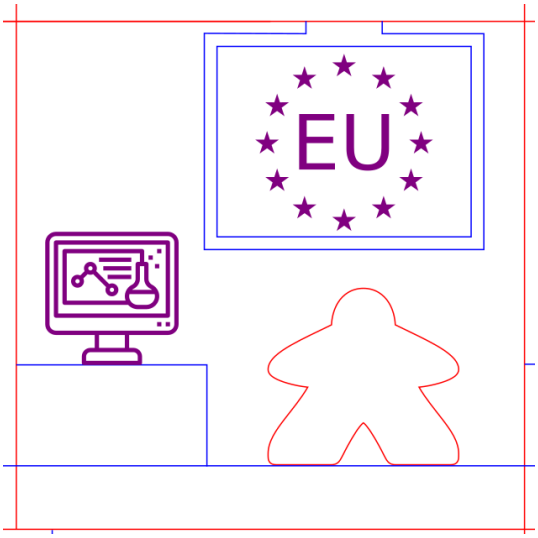

Figure B12: Publication room. Source: Léon Reboul.

Only researchers can go in this room, use any researcher (uncertified or certified) to publish a paper on knowledge you gain on (micro) plastic pollution, you gain a new uncertified researcher, choose if you want to put it in a research vessel dormitory or a land lab dormitory.

Notes:

- you must have enough beds for all your workers currently in the research vessel/land lab, the one in a trip on the submarine/fast boat/snowmobile/4x4 plus the new researcher, if not you can't accept the new researcher.
- you must have collected a new knowledge token from the laboratory room to do this action, previous knowledge do not count.

Certification room:

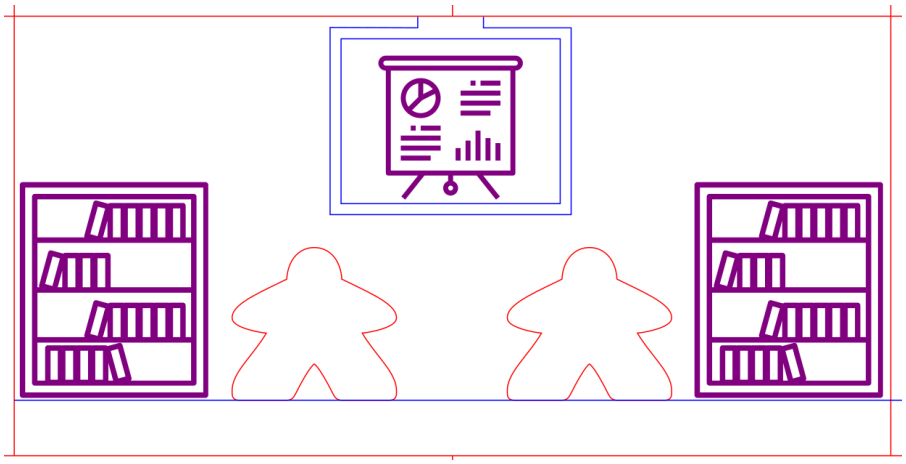

Figure B13: Certification room. Source: Léon Reboul.

All uncertified and intermediate workers can go in this room. The meeple will be kept for X days for testing in the certification room, they don't return in the dormitory at the end of the day (but you still need to count them when gaining a new researcher with the publication room action), use:

- a junior captain to certified it to a senior captain: 2 days of tests and it must have done at least one fast boat travel,
- a senior captain to certified it to a legendary captain: 3 days of tests and must have done at least one dive in the submarine),
- an uncertified researcher to certified it to:
    - a glaciologist: 2 days of tests,
    - a snow expert: 2 days of tests,
    - a junior oceanographer: 2 days of tests and it must have done at least one dive in the submarine,
- a junior technician to certified it to a senior technician (2 days of tests)
- a junior oceanographer to a senior oceanographer: 4 days of tests and it must have done at least one dive with a senior captain in the submarine.

Submarine room:

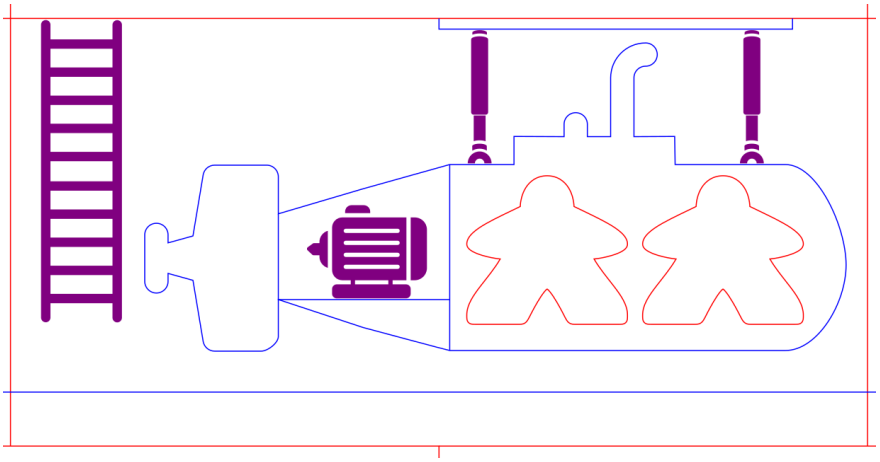

Figure B14: Submarine room. Source: Léon Reboul.

Only the captain can move the submarine, it have one more spot for a researcher, use

- a junior/senior/legendary captain to move the submarine 1/2/3 tile(s) away from the research vessel after the deployment action (crane control room), please note that the submarine can only move on water and deep-water tiles,
- an uncertified researcher to collect a water sample, the submarine must be on a water sample. Collect the sample from the general supply (blue wooden cube)
- a senior captain and a junior oceanographer to collect a water sample from the water column (grey wooden cube). The submarine must be on a water tile to do it,
- a legendary captain and a senior oceanographer to collect a water sample from the bottom of the ocean (dark wooden cube). The submarine must be on a deep-water tile to do it.

Notes:

- The meeples stays in the submarine room for as long as the mission takes.
- When unloading the submarine from the crane control room, place the submarine token on a water tile adjacent to your research vessel token. The submarine token represents the position of your submarine on the main board.
- To load the submarine back in the research vessel, the submarine token must be on a water tile adjacent to the research vessel token. Remove the submarine token from the main board and return the meeples to a dormitory room in the research vessel.

Fast boat room:

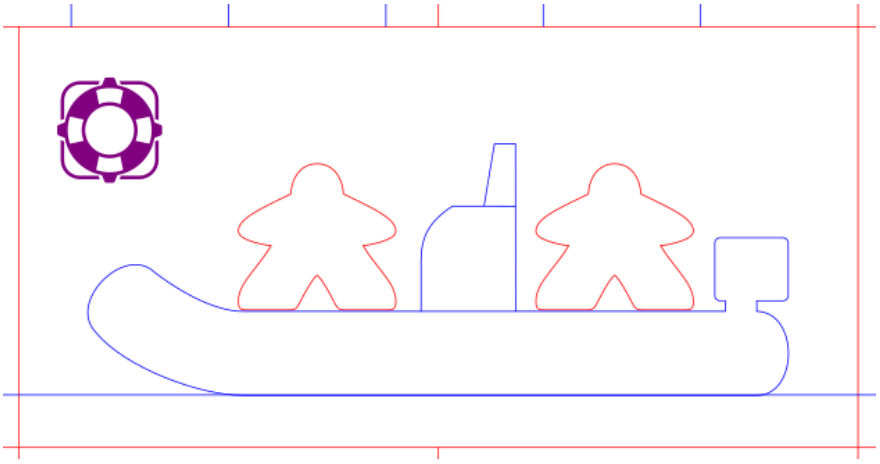

Figure B15: Fast boat room. Source: Léon Reboul.

Any worker except the technicians (you need them to operate at the crane control room or the bridge room) can go the fast boat, use:

- a junior/senior/legendary captain to move the fast boat 2/3/4 tiles away from the research vessel after the deployment action (crane control room), please note that the fast boat can only move on water, deep water and sea ice tiles,
- a researcher (certified or not) to move the fast boat 1 tile,
- an uncertified researcher to collect a water sample from a water tile,
- a glaciologist researcher to collect an ice sample (white wooden cube) from a sea ice tile.

Notes:

- The meeples stays in the fast boat room for as long as the mission takes.
- When unloading the fast boat from the crane control room, place the fast boat token on a water tile/sea ice tile adjacent to your research vessel token. The fast boat token represents the position of your fast boat on the main board.
- To load the fast boat back in the research vessel, the fast boat token must be on a water tile/sea ice tile adjacent to the research vessel token. Remove the fast boat token from the main board and return the meeples to a dormitory room in the research vessel.

3.1.2 Land Lab

Note: the rooms explained in the research vessel and present in the land lab work the same way.

Snowmobile/4x4 room:

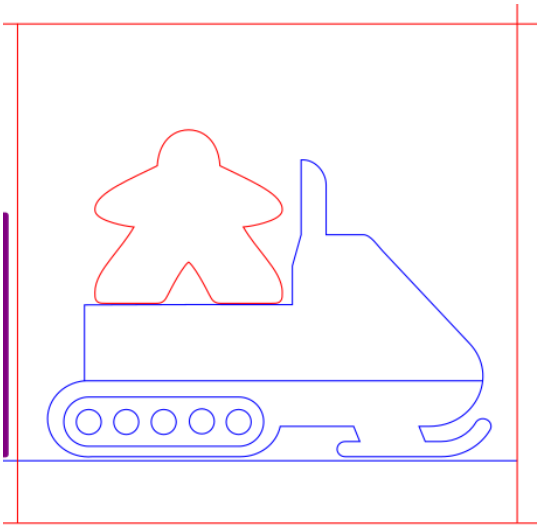

Figure B16: Snowmobile/4x4 room. Source: Léon Reboul.

Use any researcher in this room to use the snowmobile. They do not go back to the dormitory when on a mission. But you still need to count them for the beds count when doing the publication room action. Actions:

- going out of the land laboratory: take the snowmobile/4x4 token and put them on a snow (or ice)/land tile adjacent to the land lab,
- you can move the snowmobile/4x4 2 tiles per day (including the one it goes out of the lab),
- going in the land laboratory: when the snowmobile/4x4 is adjacent to the land lab you can remove it from the main board and put the meeple back in a dormitory room of the land laboratory.

4. Encounters

The following encounters can happen during the game:

- with an animal: when a researcher on a fast boat/snowmobile/4x4 encounter an animal on a tile (water/land/ice/snow), you gain an animal sample corresponding to the type of animal you meet on the tile. The first player to go to the animal token remove it from the main board and gain the corresponding animal sample token from the supply. The animal token is move back to the supply; it doesn't go to your personal board.

- with arctic communities: when a researcher on a snowmobile/4x4 encounter an arctic community meeple it can choose to spend 2 days on the tile with the meeple. If so on the third day, the arctic community meeple is removed from the board and the player gain an animal token corresponding to the type of the meeple:

    - hunters give any animal token on the board that is on a land tile. The animal token is removed immediately by the player, and you can keep it. It is the only way in the game to keep an animal token instead of animal sample token.

- fishers give any animal token on the board that is on a water tile. The animal token is removed immediately by the player, and you can keep it. It is the only way in the game to keep an animal token instead of animal sample token.

Figure B17: arctic communities' tiles . Source: Léon Reboul.

- with a hazardous tile: if you choose to cross a hazardous tile you will lose:
    - one day for a mine,
    - 2 days for a petrol rig,
    - 4 days for a military base,

Figure B18: Hazardous tiles. Source: Léon Reboul.

5. End of the game

5.1 Triggering

After an analyse action in the lab if a player has 6 or more knowledge tokens on micro plastic pollution, the game ends immediately! There is no more actions for the other players. So, I suggest that you keep an eye on other players personal board during the game!

5.2 Scoring points

Count the victory points in your personal board in two steps: first count:

- 2 points per animal sample tokens
- 10 points per knowledge tokens

them multiply your score by two for every animal token you have:

- 0 animal token: multiply your score by 1,
- 1 animal token: multiply your score by 2,
- 2 animal tokens: multiply your score by 4,
- n animal tokens: multiply your score by $2 \times n$
- 1 point for every pollution token still onboard of your ship (regardless of the colour).

Please note that if you only have animal tokens but no other tokens than your score is 0.

The player with the most points at the end of the game wins.

In case of a tie, players tied share the victory.

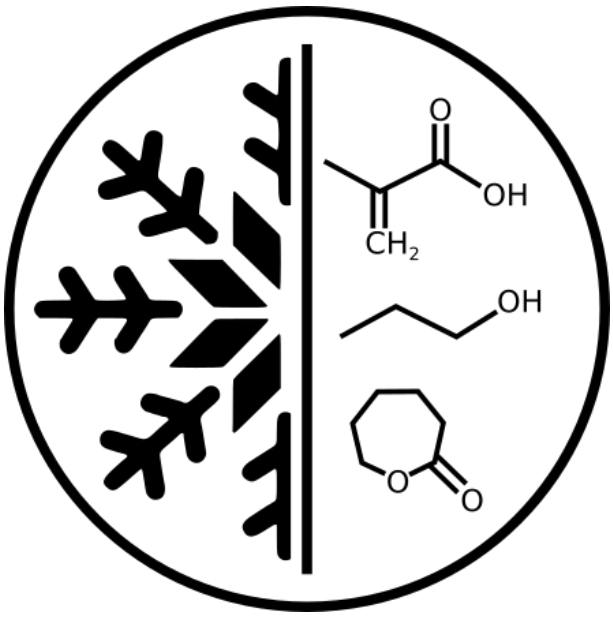

Figure B19: Best of luck with your research of pollution! Source: Léon Reboul.

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