Title: Creating a climate changed future with the sea level rise interactive- fiction game 'Lagos2199'

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Abstract:

Story-based futures serve an important role in climate change scenario development. Stories are particularly useful in exploring sea level rise possibilities, since we know many coastal areas are specifically vulnerable to accelerating rises in sea level. This discrete change in coastline is different from most other climate change impacts, and offers a clear basis for scientifically-informed, future scenarios. We demonstrate this with a creative world-building effort set in Lagos, Nigeria, in the year 2199. Further, we employ story-based scenario development, and create a learning-oriented, web-based game that allows users to experience stories in an open-ended, text-based adventure style. This collaborative process blended scientific research, story-telling, and artistic co-creation to iteratively construct the game 'Lagos2199'. The first use-case of Lagos2199 is documented herein, with corresponding survey results from the student users. This work has three core conclusions. First, the unique reality that sea level rise will literally re-draw maps can be leveraged as an entry-point for world-building and scenario development of the future. Second, such a scenario can be blended with storytelling, art, and music to create a multi-dimensional, immersive exploration of ecological and social change. Third, this kind of game experience can serve an important pedagogical role in climate change education. Providing the next generation of citizens with fluency in both climate change impacts and how society will interact with such impacts, is critical for providing adaptive capacity over the coming decades and centuries of accelerating global change.

1. Introduction

Climate change impacts to the Earth system will be far-reaching and consequential to every aspect of human society (Wuebbles et al. 2017, Steffen et al. 2018). Recognition of these impacts, however, has not led to a commensurate effort to educate future generations to understand and prepare for a new world (e.g. Gillenwater 2011, Monroe et al. 2019). Part of this challenge is due to the fact that climate change is becoming an all-encompassing reality with heterogeneous impacts globally (Vincent and Hamilton 2020). Temperature changes may increase dramatically, or modestly, depending on the location of the planet, and the season being considered (Dai 2012, Mueller et al. 2016). Precipitation and drought are also notoriously difficult to frame effectively, given that some parts of the world are likely to get wetter (Giorgi et al. 2011, Allan et al. 2020), while drought will get worse in other parts of the world (Fu et al. 2013, Findell et al. 2019).

Global increases in mean sea level will, contrary to other impacts of climate change, unfold more consistently around most of the planet (Kopp et al. 2019, Levermann et al. 2020). While the range of sea level rise scenarios is indeed quite wide (Church et al. 2013), the geophysical location of these impacts is concentrated along the relatively narrow area of land that will or will not be inundated (Hsiang et al. 2017, Hauer et al. 2019). Moreover, given that global humanity is concentrated in larger numbers on coastlines, compared to inland areas, sea level rise is highly consequential for the global economies, cultures, and political stability in the future (Rigaud et al. 2018, Bell et al. 2021). Despite this, there remains a persistent lack of educational resources for this topic.

Games have been widely used as a method for providing educational resources for learning about and practically working through climate change impacts and adaptation (Flood et al. 2018). Serious games, so-called since they are explicitly for purposes other than entertainment, have been used for increasing capacity among policymakers as well as for stakeholder engagement (Wu and Lee 2015). Climate change education has also been a focus of such effort, including the development of serious games in the classroom, as well as focusing on the purpose of games for fostering deeper connections

toward human-environment challenges (Abraham and Jayemanne 2017, Barnes et al. 2017).

Unlike some serious games, which are explicitly focused on team-work and decision making, narrative-rich, story-based games can also provide important contributions to climate change education (McComas and Shanahan 1999, Spoel et al. 2008). Storytelling based scenarios have emerged as a key feature of futures thinking globally, ranging from industry to government to education (Rasmussen 2005, Sakakibara 2010, Milkoreit 2017). Specifically, science fiction prototyping has emerged as an effective vehicle for creating engaging and immersive visions of a radically different future from the present day (Johnson 2011, Burnam-Fink 2015, Merrie et al. 2018). Likewise, approaches such as the 'Seeds of a Good Anthropocene' and the 'Nature Futures Framework' employ creative scenario approaches that intentionally focus on trajectories toward a more sustainable future (Pereira et al. 2020a, 2020b).

Nuanced, complex, and sometimes contradictory pathways are critical to properly envisioning a future — particularly in parts of the world that are often sloppily-depicted as a single story and in a negative light (Adejunmobi 2016). Science fiction has contested ideas of a globalized, western idea of the future (Csicsery-Ronay 2012). Particularly, African science and speculative fiction has emerged as a dominant locus of decolonial and endogenous ideas about African futures, fostering robust debate and discourse (Thompson 2017, Hugo 2017, Serpell 2019). In parallel with the contemporary recognition of the historical and topical depth of African science fiction, is the present day reality that many parts of West Africa are demographically the fastest growing, and are among the most economically dynamic in the world (e.g. Rosling 2019). In particular, Lagos, Nigeria, has emerged as a focal point for global ambition, economic development, and local narratives contesting western perceptions of development (Hecker 2010, Shiru et al. 2020). For these reasons, situating narratives about future worlds, especially worlds that characterize local agency, are of paramount importance for adequately reflecting reality in climate change education (Pereira et al. 2018).

In this work, we leverage cutting edge research on the long-term inundation caused by sea level rise in the Lagos region of Nigeria. Then, we use Science Fiction Prototyping and other futures methods to generate an engaging, scientifically-rooted story of the future of Lagos, informed by the latest scientific

84 projections of climate change (Fashae and Onafeso 2011, Brown et al. 2017, Croitoru et al. 2020, Shiru et
85 al. 2020). We then transform the story into a text-based game, blending storytelling, visual art, and music
86 to create an immersive experience about a future Lagos set in the year 2199, called 'Lagos2199'. The first
87 use-case of this game is captured using a survey of students that have actively learned about sea level rise
88 and climate change, prior to playing the game.

89 We have three core findings in this work. First, the unique reality that sea level rise will literally
90 re-draw maps can be leveraged as an entry-point for world-building and scenario development of the
91 future. Such a scenario can be blended with storytelling, art, and music to create a multi-dimensional,
92 immersive exploration of ecological and social change. Third, this kind of game experience can serve an
93 important pedagogical role in climate change education.

94 The layout of this paper is a bit unorthodox, since we are describing an iterative and creative
95 process of story and game development. Thus, we have sections that first describe the quantitative process
96 of sea level rise projection to 2199, followed by a description of the iterative process we employed for
97 developing the story, incorporating the game platform, designing character art, rendering conceptual
98 environments, and identifying suitable musical accompaniment. Then, we report on a brief survey of the
99 game's first users. Finally, we discuss Lagos2199 in the context of climate change games, futures
100 research, and art-science collaboration.

101 2. Creating the geography of a future Lagos

102 *2.1 Theoretical estimate of sea level rise in Lagos, Nigeria*

103 First, we identify an inundation scenario that is consistent with an Intermediate projection of sea
104 level rise for 2200 (Sweet et al. 2017). While global mean sea level (GMSL) will not be precisely true
105 anywhere, because of relative differences in e.g. topography and bathymetry, it is a suitable proxy for a
106 conservative estimate of sea level rise in low-lying areas such as Lagos, Nigeria (Kopp et al. 2014). Thus,
107 using an intermediate scenario, we find that sea levels will likely rise by 2.8 meters globally.

Locally, sea level rise will be experienced through high tide, and annual flooding events. In Lagos, the average high tide is slightly less than 0.5 meters above mean sea level (Melet et al. 2016). Thus, under an Intermediate sea level rise scenario, of 2.8 meters, plus a regular high tide of ~0.5 meters, the typically inundated area for Lagos in 2200 will be above 3.0 meters. For the purposes of this analysis, and simplicity in subsequent steps, we round the amount of change to 3.0 meters.

2.2 Climate Central inundation mapping

Next, we use Climate Central's coastal risk screening tool to map inundation in the Lagos, Nigeria region (from https://www.climatecentral.org/) (Kulp and Strauss 2019). These maps are a combination of (a) high resolution satellite imagery (NASA JPL 2013), (b) existing sea level rise analysis (Tebaldi et al. 2012, Kopp et al. 2014), and (c) proprietary sea level rise projections made available for educational and research use (Strauss et al. 2012). We use the Climate Central inundation map to reveal both the current coastline of Lagos (Fig 1a), and a projection of sea level rise in Lagos based on the theoretical rise of 3 meters (Fig 1b).

We had considered using a more direct projection of sea level rise that can be tethered cleanly to unique climate change projects (such as the Intergovernmental Panel on Climate Change Representative Concentration Pathways, IPCC RCPs). However, at the time of our use of the Climate Central platform, the inundation scenarios did not extend beyond 2100.

2.3 Simple GIS approach of modifying a DEM

While the Climate Central map for 3 meters of sea level rise demonstrated profound inundation of the Lagos region, we were not able to export the map for use in the Lagos 2199 game. Thus, we complemented the Climate Central spatial estimate of inundated areas with a simple analysis based on a digital elevation model (DEM). We used digital elevation data that is based on the Shuttle Radar Topography Mission with information at the 90 meter resolution (NASA JPL 2013). In this DEM, the data indicated the height above (or below) sea level. This information is visualized in software with colors

corresponding to different elevations. Figure 1c shows the current coastline of the Lagos region, with black corresponding to land and white corresponding to water.

Thus, our sea level rise map for the Lagos region was produced by changing the symbology in QuantumGIS (i.e. QGIS, a freely-available geographic information system software) to indicate that water started at the 3 m elevation level in the DEM, rather than zero (Fig 1d). While this is a straightforward and somewhat simplified approach, the map that is generated is nonetheless very useful for showing which present day cities and areas of the Lagos region may be underwater under an intermediate projection of sea level rise (Sweet et al. 2017). Likewise, it is possible to see the profound change simply by adjusting this color scheme in the DEM, and to provide a new sense of which lands are inhabitable on dry land and which areas will be more or less permanently under water. This simple, straightforward approach allows us to use spatially georeferenced data layers that are readily available (e.g. locations of cities, roads, etc), if we wanted to add them to the map.

2.4 Cross-check between Climate Central and GIS-based estimates

By comparing an overlay of the Climate Central estimate of sea level rise, and the simple DEM-based estimate, we find high correspondence (Fig 1e). While there is some disagreement, particularly in low-lying portions of western mainland Lagos city, the pattern and extent of inundation is highly consistent. Thus, we have high confidence in the base map of the Lagos region as well as the future map associated with 3 meters of sea level rise (Fig 1f)

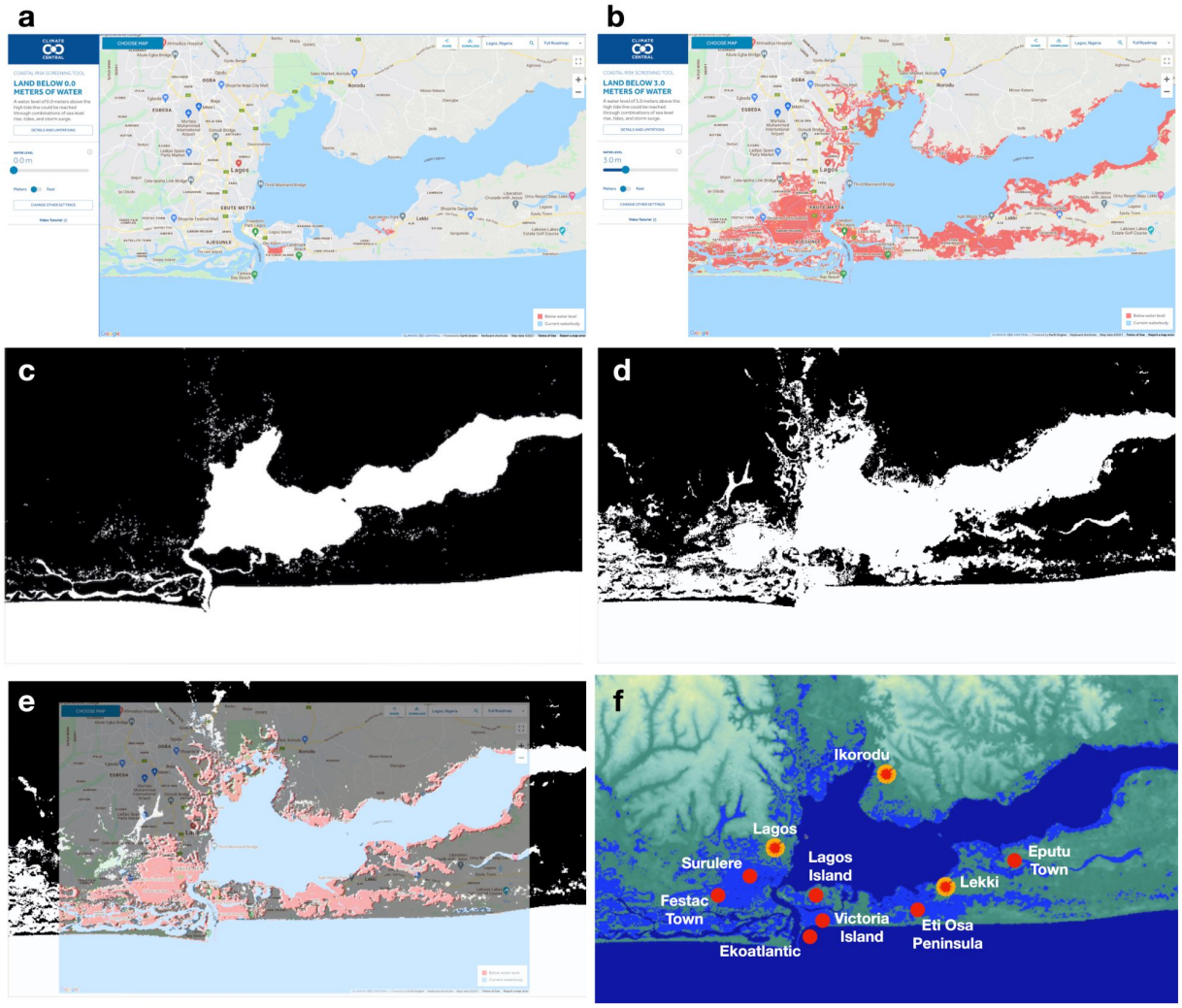

Figure 1. Mapping process of Lagos region, from top left, a) current coastline from Climate Central inundation map, b) potential coastline from Climate Central inundation map associated with 3m of sea level rise, c) current coastline without DEM modification, d) potential coastline with DEM modification representing 3m of sea level rise, e) overlay of potential coastlines from Climate Central and DEM modification, and f) finalized map showing 2021 and 2199 inundated areas with 2021 inundated areas in dark blue, and 2199 inundated areas in lighter blue.

2.5 Map of Lagos present day vs. 2199

The map presented in Figure 1 illustrates how profoundly Lagos will be transformed with 3 meters of sea level rise. Using QGIS, we are able to depict this change with the dark blue colors

corresponding to presently inundated area, light blue corresponding to newly inundated area by 2199 and the green colors corresponding to areas above the hypothetical, 2199 high tide.

Between the present day and 2199, the Lagos Lagoon is transformed into Lagos Bay. In the present day, the entry to Lagos Lagoon is a clear waterway between the southwest area of the Lagos Port, and areas on the eastern side such as Eko Atlantic, Victoria Island, and Lagos Island. In the future, the channeled waterway forming an entry into Lagos Lagoon becomes a fractured coastline of semi-inundated areas. The areas of Victoria Island and Lagos Island (center of the south-facing coastline) now appear to be open water, though would likely be marshy, highly vegetated areas. Likewise after 180 years of sea level rise, this region may be unnavigable due to changed and collapsed infrastructure in the region. Further into the lagoon, the western part of Lagos that contains Surulere, Festac and other regions (left hand side of map), are inundated almost entirely, forming a small bay. The other area in the region that is more transformed than most of the other areas is the Eti Osa peninsula in the southeast (center to the right side of the map). Administrative areas such as Lekki, Eputu, and others have been massively inundated by 2199.

While it is possible to use existing spatially georeferenced data layers in a GIS analysis, we use the present locations of cities and major social focal points, as suggestive rather than indicative of future locations. In other words, we allow for the fact that in the next 180 years the current structure of habitation and population will adjust to changing sea levels. While at the same time, recognizing that cities are remarkably persistent, despite enormous disasters and changes (McGranahan et al. 2007).

3. Game development: story, characters, art, music

3.1 Worldbuilding

The setting, or world, for the Lagos2199 story was developed using a systematic, structured futuring approach, which was adapted for the specific purpose of generating a story from sea level rise-induced changes. To be clear — the story creation process was iterative and generative, meaning that the

187 relatively linear path shown in Figure 2 is described with retrospective clarity. First, as previously
188 mentioned, we used the modified DEM and existing spatial data on points of interest, cities, and other
189 landmarks to learn what the new geography of 2199 could be. Using the map of the Lagos Bay in 2199,
190 we focused on the transition of three major regions from the present to the future, specifically: Lagos
191 becomes Eko City, Ikorodu becomes Ikorodu City, and Lekki becomes New Lekki City (red dots with
192 yellow outlines, Fig1f).

193 Second, we imagined how these three cities of the future might possibly appear in 2199, and we
194 brainstormed how the ideas might be connected to one another in the future (Fig 2a). We looked for both
195 logical and contradictory connections (Pereira et al., 2018). Part of the future wheels approach was to try
196 and identify first order details related to these future cities, followed by secondary, and tertiary details.
197 For example, what distinguishes Eko City in the future? It is the largest and oldest part of the region, and
198 this informs the cultural and social role that it plays. Likewise, the progressive inundation has continually
199 remade New Lekki such that it has emerged as a dynamic and changing metropolis.

200 Third, the three horizons framework was used to explore "patterns of innovation and change
201 through a systems lens" (Curry 2015, Sharpe et al. 2016). The three horizons were the present world, a
202 transition period, and the future world (i.e. the target time period of the story) (Fig 2b). We used the three
203 horizons framework, to situate the three cities in 2199 (at the fully-realized, third horizon) and to design a
204 future history characterized by systemic changes that propel the entire region. Working backwards, we
205 identified how the world has transformed from the present day to the hypothetical future world. We then
206 focused on three specific points in this future history, where the first, second and third lines intersect. The
207 intersections were first that (a) in the mid-late 21st century Nigeria develops cutting edge
208 biotechnological tools to mitigate carbon emissions, (b) a meltwater pulse event leads to catastrophic sea
209 level rise at the end of the 21st century, and (c) in the early 22nd century The three cities that comprise
210 Lagos Bay become independent from the Nigerian national government. These three core ideas are
211 complemented by other ideas that are featured in the full three horizons chart, and also served to further
212 modify the map.

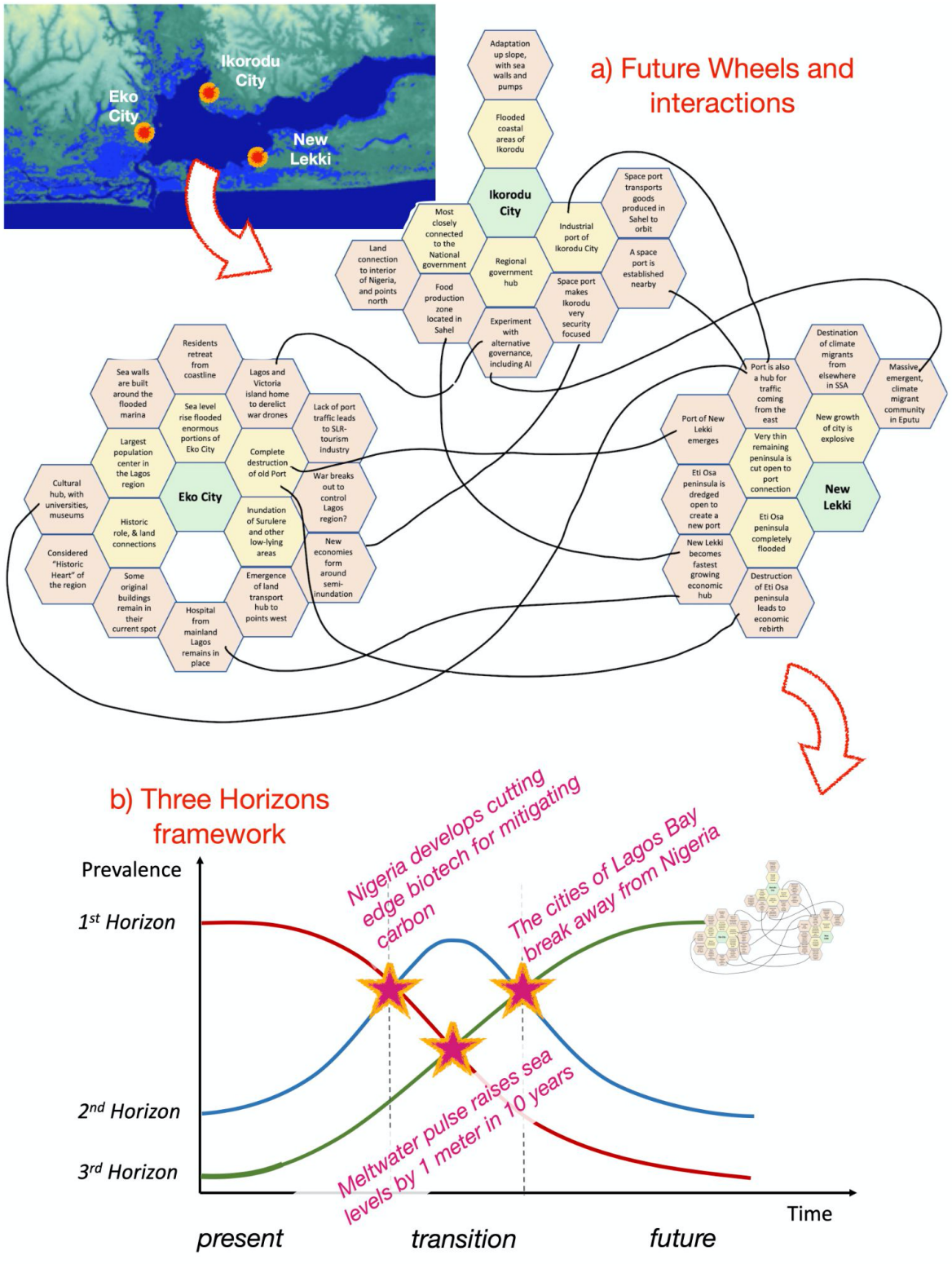

Figure 2. Worldbuilding; a) first creating from the initial map of Lagos2199, with the Future Wheels and interactions, followed by b) the Three Horizons framework. These summary figures are meant to visually convey the approach.

3.2 The moral of the story

Based on the structured futuring procedures above, we revised the map of Lagos 2199, and identified the preliminary 'moral' (or point) of the story. In this case, the point was for a water taxi operator, who ferries people around Lagos Bay, to reveal how things have changed in the future, owing to climate change and more. With an emergent sense of the future of Lagos, the nascent story, and a sense of how the history has unfolded, we zoomed-in on key waypoints throughout Lagos Bay. We made sure each waypoint served a specific narrative goal and illustrated a particular climate change or sea level rise feature (Table 1).

Table 1. Summary of Lagos Bay waypoints, the relevance to the narrative structure, and the specific sea level rise (or climate change) -related feature that is highlighted.

LAGOS BAY WAYPOINT	NARRATIVE GOAL	SEA LEVEL RISE FEATURE
Eko City	Historical heart of region	Persistence in face of sea level rise
Ikorodu City	Artificial General Intelligence	Technological adaptation for complex circumstances
Space Port	Space-faring civilization	Technological advances despite climate change
Eputu Town	Persistent, adaptive slum	Social dimensions of climate refugees and migrants
New Lekki	African megalopolis	Rebuilding following sea level rise disasters
New Lekki Port	Transit connection to Africa	Adaptation to sea level rise and infrastructure collapse
Ekoatlantic Ruins	Hubris of the past	Legacy of failure to consider long-term risks of sea level rise
Atlantic Point Base	Military resurgence	Emergence of military governance during and after sea level rise
Snake Islands	Port infrastructure collapse	Permanence and difficulty of dealing with old infrastructure
New Festac	Inundated community	Adaptive community and restorative economics
Old Lagos	Legacy of regional warfare	Historic legacy of sea level rise and climate change conflict
Bat's Mouth	Biotechnology hub	Local scientific advances to mitigate climate change
N'etiti (Bat Forest)	Religion merging with action	Re-alignment of culture to make sense of existential crisis of climate change and sea level rise

Using the expanded set of waypoints detailed in Table 1, we began developing the story that occurs throughout Lagos Bay. Given that the user's character in this game is a water taxi operator, we decided that the story should unfold in a way that makes logical sense from the perspective of somebody taking passengers around the bay. As such, the sequence of waypoints featured in Table 1 is the same order in which they are encountered in Lagos2199. Thus, beginning with Eko City, the story proceeds clockwise around the exterior of Lagos Bay, before concluding in the interior of the Bay. The development of the story plot was iterative, and early versions of the story involved a more complex navigation of the bay. However, given that the central character in this story is a water taxi driver who is navigating around the Bay, we wanted to avoid duplication of locations within the story, and provide the maximum exploration possible within a single day.

3.3 Characters of Lagos Bay

As the geographic and worldbuilding of the story became clear, so did the supporting cast of characters that the water taxi operator encountered along the way. These characters helped to propel the narrative forward, provided information about the world, and motivated the action and events of the story. Table 2 shows the specific characters that are picked up and dropped off around Lagos Bay, and emphasize the narrative role they play in the story.

Table 2. Overview of characters that the water taxi operator transports around Lagos Bay.

CHARACTER	PICK-UP	DROP-OFF	NARRATIVE GOAL
Business person	Eko City	Space Port	Explain there is a problem in Lagos Bay related to dying Bat Forest
Student	Space Port	Eputu Town	Explain purpose of Bat Forest with regard to climate change mitigation
Soy vat scientist	Eputu Town	New Lekki	Provide glimpse of possible scientific reason for dying Bat Forest
Coast Guard officer	New Lekki	Atlantic Point Base	Explore the danger of scofflaws in the Bay, as well as the tension between the Three Cities and the Nigerian government
Tourist	New Lekki Port	Snake Islands	Comic relief. Also, providing an outsider's perspective for some of the sea level rise damage to the bay
Drone Technician	Atlantic Point Base	New Festac	Explain the Lagos War, and the ways technology has acreted around the Bay
Gene Edit dealer	New Festac	N'etiti (Bat Forest)	Dramatic tension for the Third Act of the story, where the mystery of the sick Bat Forest and other things get resolved.

3.4 Build story beats and write story

The worldbuilding, the waypoints that the story explores, and the characters the water taxi operator encountered in the game all provided the scaffold for writing the story. We created the outline of the story by defining the core story beats that would help distribute the events of the story, where and how the characters interact with the water taxi operator, and how to provide a satisfying story experience. This helps shape the arc of the game narrative, and ensure that text effectively delivers on the primary goal of the story. Here is a brief overview of seven key story beats, which begin in italics:

1. *Once upon a time,* there was a normal water taxi operator in Lagos Bay.
2. *Every day*, the water taxi operator would perform this uneventful job, while trying to avoid dangerous areas, like Old Lagos and the Bat Forest.
3. *Until one day,* the water taxi operator happens to be assigned a very fancy boat, which is out of the ordinary.
4. *Because of this*, the taxi operator can travel much further around the bay, and has a string of unexpected Fares that know information about the Bat Forest.
5. *Because of that*, the taxi operator becomes tangled up in a mystery involving Old Lagos, biotech, and the dying Bat Forest, with a Drone Tech and a Gene Edit dealer.

6. *Until finally,* the taxi operator winds up solving the mystery of why the Bat Forest is dying.
7. *Ever since then*, the taxi operator has a deeper involvement in what happens in Lagos Bay and a greater awareness of their role in things.

This list of story beats then provided the framework that the story was woven around. To be very clear, the story had to make sense, but also deliver a satisfying text-based game experience. So, while the description that is conveyed in this article suggests the entire process was directed and linear, the writing process was a circular loop of drafting, testing in the Twine game software (detailed below), experimenting with music and art, and returning back to revising the story itself.

The full text of the story is available as a separate Supplementary document. We emphasize, however, that certain aspects of the story leverage the fact that the user themselves must interact with the story by making choices, all while seeing the visuals, and hearing the game music. Thus, the text is most effectively experienced in the game context.

3.4 Make it Weird

Finally, the story was examined for how well it managed the tension of remaining realistic, while also being strange. Following Dator's second rule of Futures Research, "any useful statement about the future should at first appear to be ridiculous", we aim to imagine a world that has elements that are wholly different from the present (Dator 1993, 2019). At the same time, certain features of the present may be too permanent or unchangeable to convincingly transform (O'Neill 1981). Thus, we aimed to balance the story to push the limits of what is believable or possible, while not going so far as to have the reader disengage. It is worth noting that this is not a process of science *fact* prototyping, but science *fiction* prototyping, and as such we leaned into the fictional approach. In this case, with a world that is 180 years in the future, it was critical to make certain aspects of the technological and socio-political world very strange. Thus, some elements took on a fantastical component, including:

- The Ikorodu government is managed by an Artificial General Intelligence,
- Nigeria, and Lagos in particular, is a leader in genetic engineering,
- West African governments are different from present day geopolitics, including Lagos Bay which is a city-state autonomous from the Nigerian national government,
- Climate change has led to migration crises *from* Europe *to* Africa, and
- Humanity has colonized the inner solar system, including orbiting colonies around Mars.

These aspects are definitely fictional, yet also theoretically or scientifically plausible. Given the far timeframe in which this story is set, sufficiently capturing the potential for strangeness is critical (Dator 1993, 2019).

3.5 Game design

Following the development of the initial scenario world, we needed a freely-available, open access, and user-friendly game platform. We used the Twine software to develop the game. Twine is an open-source, text based software that has its own, internal coding languages (e.g. SugarCube 2.0), and also can incorporate common internet coding languages, i.e. HyperText Markup Language (HTML), Cascading Style Sheets (CSS), and Javascript. The platform is highly customizable and permits flexible pathways for a click-based story, and is reminiscent of early, text-based adventure games from the late 20th century. The Twine platform incorporates a graphical user interface, presented as a flowchart of discrete 'Passages' (i.e. story components) and connections that link the passages (Fig 3a).

The game development was, necessarily, highly iterative. Originally, the game was planned to be a multi-branching story, such that the water taxi driver could go in nearly any direction within Lagos Bay. However, this was halted, given that such a game would not permit a common user experience nor a structured exploration of the game world. A key goal of the game development was to foster a common user experience in terms of both the storytelling and the exploration of climate change impacts to the

region. Thus, a single-path story was developed, with minor branching elements.

Example ‘Passages’ from the final Twine game are shown in Figure 3. This is absolutely not meant to be a comprehensive explanation of all the code in Lagos2199. However, we highlight how Twine blends its own coding language (in this case, Sugarcube 2.0) with HTML and Javascript. First, the game often provided the user with multiple options to explore, as depicted in Fig 3b, where the user is deciding whether or not to pick-up an item. Another element visible in Fig 3b is the command to play or stop music within that panel. Second, there are specific commands to display imagery, including the character artwork (Fig 3c). This used additional HTML code and referenced a web-based data server (see details below). Third, the user in Lagos2199 navigates the region via a clickable map (Fig 3c). This required using a process of mapping an image’s pixels, and then identifying which part of an image would connect a user to a different passage. The game design process required a great deal of trial and error, to make sure that the many different elements of the game, including music, imagery, and game logic were all correctly rendered during user gameplay. Furthermore, this was a quintessential example of ‘learning-by-doing’, in the sense that the authors have never developed anything like this before, and thus existing web-based Twine user forums were critical for creating the game.

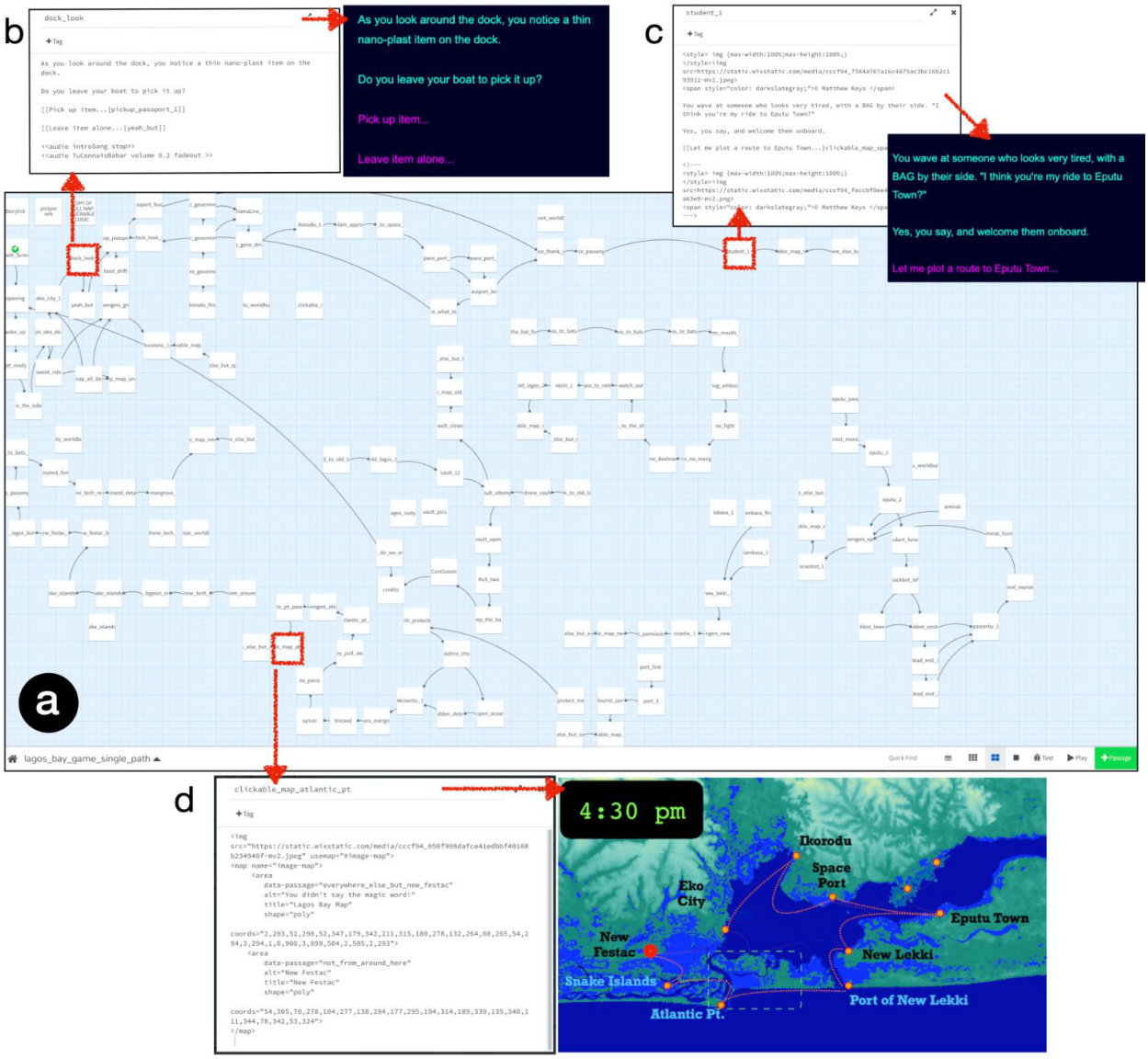

Figure 3. Twine game interface, with a) the main screen showing the overall flowchart of the Twine game, b) an example passage with two options a user can click with the corresponding game screen, c) an example passage where the user meets a character with the corresponding game screen, and d) an example of the clickable map interface within the game with the corresponding game screen.

3.6 Character art and development

Given the goal of an immersive game experience, and that the player of the game is the water taxi driver, special attention was paid to the development of the characters that were taken around Lagos Bay

(Table 2; Fig 4,5). In general, characters were designed to propel the story narrative, aiming to both provide a reason for movement around the bay (i.e. picking up and dropping off passengers), and narratively increase the stakes of the story.

Initial concepts for each character were developed, and iterated until the final art was complete. Importantly, as the character art was developed, this process modified the narrative itself. This feedback between art and scenario development was very important for the final game experience, and emphasized the need for responsiveness and narrative agility in story-based narrative design. The user does not have a visual character in the story. This was intentional to allow any user to project themselves into the role of the water taxi operator.

To start the design process for the non-player characters that would populate the game, a synopsis of each character was drafted including details about who they were, what part in the story they played and a short list of descriptive details of appearance to provide a jumping off point for creating designs. There was no specific gender or age assigned to any character, but that eventually came out organically through the creative process. Reference material was significantly used to capture modern day clothing, which would then be given futuristic aspects for the setting. This included taking the Nigerian Agbada and giving it a more fitted look for the businessperson character, and a more loose and stylized look for the tourist character. Modern day Nigerian military uniforms were used as reference for the Coast Guard character, allowing for the creation of a uniform for a currently non-existent branch of law enforcement in Lagos prior to the sea level rise event of the game.

The characters were initially hand-drawn, the drawings then shared with the game design team for review before further work would be done to digitally ink and color the drawings. This was an important step to allow opinions of the group to be voiced about the design of the characters and any aspects that did not fit in the narrative.

For example, one character was visiting the Lagos Bay area from the Lunar University on the Moon, and the initial design included the torso of a partially disassembled space suit (Fig 4a). However, upon discussion, a space suit would not fit the heightened temperatures that global warming would be

exhibiting in the year 2199, particularly in tropical Lagos. This led to the character having a more skin-tight suit with a vest; the vest having patches identifying Nigeria, the Lunar University and the activist stance of the character (Fig 4b). This enriched the character's background more than identifying the character coming from space by wearing a spacesuit.

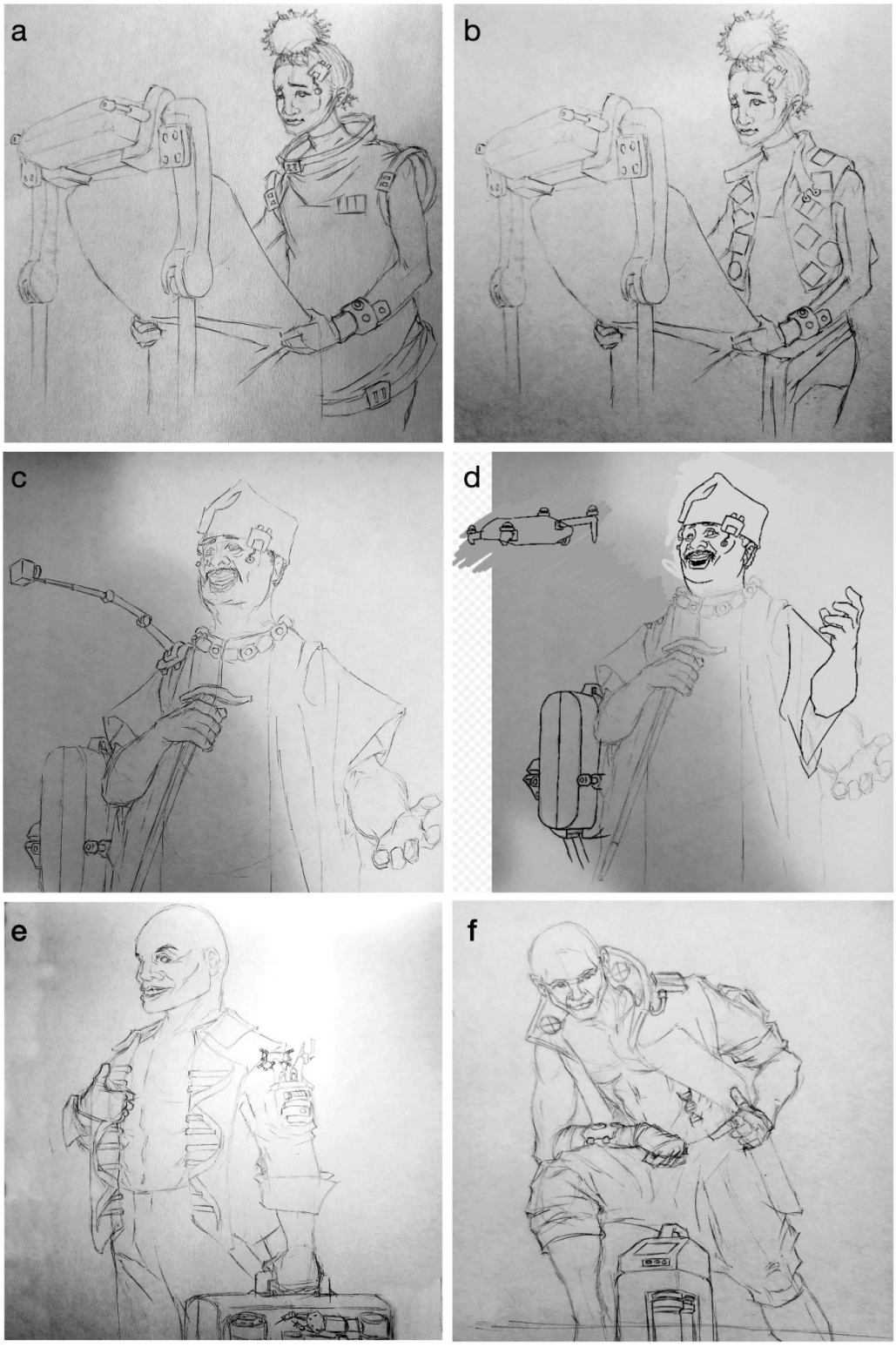

Figure 4. Example of character development process for a,b) the Student from the Lunar University, c,d) the Tourist, and e,f) the Gene Edit dealer.

Additionally, small modifications were made to make characters more expressive. Through the character design process, using the digital inking mechanism to make modifications was helpful in that the original hand-drawn design did not have to be modified, all adjustments could be made digitally. For example, the tourist character is actively vlogging and orating, and to make the character more futuristic and more expressive, the camera on selfie stick and lowered arm were digitally edited out and replaced with a vlogging drone and raised arm (Fig 4c,d).

Other times the initial concept did not really hit the mark, such as the gene edit dealer. Initial concept was too overt in design, had anachronistic tools, and did not suitably convey potential menace (Fig 4e). In this case, a new concept was drawn up, allowing the character to covertly reveal their status as a Gene Edit dealer, the tools of the trade looking more streamlined and futuristic (Fig ef).

Once the design was agreed upon, the digital inking and coloring occurred. This included the use of a pressure-sensitive pen tablet such that the line work in the digital inking would look drawn rather than have a static width. In the digital drawing application, it allowed for different layers to be added to the artwork, allowing the inking to occupy layers separate and above the coloring layers. The artwork could then be broken up into foreshortened pieces, each piece worked on separately, allowing quick rework to be done on one piece without affecting other pieces. The layers having transparent backgrounds allowed for making semi-transparent elements such as the holographic screens present in many of the character designs.

Coloring for clothing and peripherals was done in a comic book fashion, with simple shadows to make the images more pronounced. In contrast, multiple references were used to capture the diversity of skin tones of the characters, and the skin was inked using a more blended approach giving it a softer feel. Digital color palettes were made to keep colors consistent between the different layers of the digital art. Four final character renders are shown in Figure 5.

Figure 5. Example of four characters in the story that illustrate social, economic, and technological changes in the future.

3.7 Environment and concept art

Using photographic material that is in the public domain or under permissive Creative Commons licenses, we created immersive artwork to accompany the stories. Given that the future depicted in the story is radically different from the existing world, these photos were manipulated using the freely

available GNU Image Manipulation Program (GIMP). The manipulation of the photos ranged from simple application of preset image-manipulation filters within the GIMP program, to multi-image composites. For example, the environment for Old Lagos (a waypoint in the game), includes photographic sources that were digitally manipulated in GIMP (Fig 6).

Figure 6. Example of the components of a multi-image composite including a coastal lighthouse, destroyed and decaying buildings, and tangled vegetation. While these source images are blended throughout the composite, elements from the originals on the left are indicated in the composite on the right.

Thirty-eight pieces of concept and environment art were developed for the final game, and this art is available in the Supplement, including corresponding photographic references, source artist name, and the relevant license governing the use of each source. Four examples of the types of environment and concept art used in the game are shown (Fig 7).

Figure 6. Example of four pieces of the story art that visually depicted the changed landscape of Lagos 2199. Clockwise from top left: a color-shifted image of the city of Bat's Mouth, flooded forests in N'etiti, decaying Old Lagos, and flooded port facilities near the former Lagos port complex.

3.8 Musical score

The story was complemented by music from the open access Free Music Archive, which is a database of freely available, creative commons copyrighted music. Songs were selected to accompany the different locations around Lagos Bay to match the situation in the story, dramatic tension, and tone. All

songs used were done so in a manner consistent with the individual Creative Commons licenses associated with each song. The full list of songs, artists, and individual licenses is available in the supplement.

3.9 Web-based gameplay

Given that the game would be played on the web, it was necessary to have the game *assets* (i.e. artwork, music, etc) also available on the web. Thus, a web-server was set-up using a free website, with all game assets loaded onto this website. In this way, the Twine game could reference the assets on the dedicated web server, from anywhere in the world, and without having to download anything to a local machine. In the case of Lagos2199, the Wix web platform was used to host the data for the duration of the project.

3.10 Go play 'Lagos2199'

The final game is freely available at the link https://climate_futures.itch.io/lagos2199 and we encourage you to explore the game for yourself. Gameplay requires about 30-60 minutes of time, depending on how long you take to navigate the various pathways. The game itself is released under a Creative Commons License Attribution 4.0 International (CC BY 4.0). This license permits users to share and adapt Lagos2199, providing they provide Attribution to the creators.

4. First use-case of 'Lagos2199'

4.1 Preparation and approval for documenting first use-case

One of the co-authors on this manuscript, teaches an annual, upper-division undergraduate course on sea level rise. Given that one of the learning modules in this course is focused on climate change in Lagos, Nigeria, it was deemed useful to test the efficacy of this learning game with a subset of the students.

In order to conform to ethical norms in research, the survey questions and methodology were submitted and approved by the author's Institutional Review Board. All relevant ethical guidelines were observed, and the user responses were (and remain) anonymous. A total of 15 participants were invited to provide feedback on the initial game, and 12 respondents actually provided feedback and user data. None of the user responses contain identifiable information nor are they publicly available, excepting as presented in this article.

Participants were instructed to play 'Lagos2199' and at the end of their version of the game, there was a link to take a survey. This link took the participant to a Google Forms-based survey. The survey questions included a Likert scale ranking of agreement with four different statements, as well as open-ended questions to gather additional thoughts and reactions. For the Likert scale questions, participants were encouraged to rate their level of agreement with the statements, ranging from 1 corresponding to 'strongly disagree', with 4 corresponding to neutral, and 7 corresponding to 'strongly agree.'

The survey is available in the Supplementary Information.

4.2 Survey results

The results of the survey indicate that the Lagos2199 game was broadly effective at improving students ability to visualize and consider sea level rise in Lagos, Nigeria. First, the majority of students disagreed with the statement that prior to playing Lagos 2199, they could easily imagine future life in Lagos (Fig 8a). Likewise, after playing the game, the majority of students agreed that they could (now) easily imagine future life in Lagos (Fig 8b). Second, most students agreed that the story in Lagos2199 effectively conveyed climate change in Lagos. However, a quarter of respondents were neutral on this question. Third, a majority of students either agreed or strongly agreed that the story was effective at conveying sea level rise in Lagos.

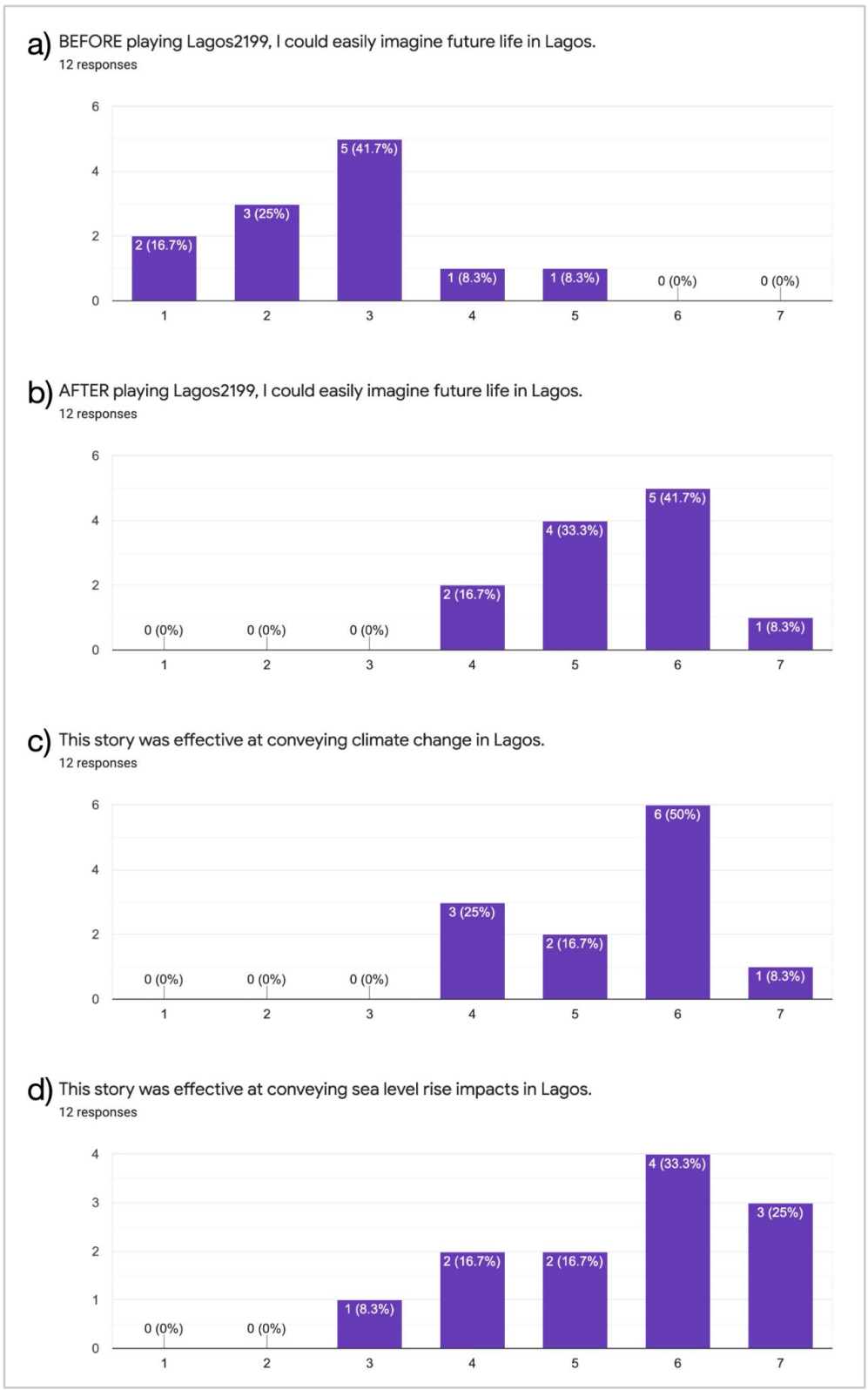

Figure 8. Summary survey results from the first use-case of the Lagos2199 game. The scale ranges from 1 = 'strongly disagree', 2= 'disagree', 3= 'somewhat disagree', 4= 'neutral', 5= 'somewhat agree', 6= 'agree', and 7= 'strongly agree'.

The survey yielded some negative results as well, notably that one student 'somewhat disagreed' and two students were 'neutral' on whether Lagos2199 was effective at conveying sea level rise impacts in Lagos. This represents fully a quarter of the participants, and while the majority thought the game was effective (9 of 12 respondents), it is worth noting that there could be improvements to the communication of the sea level rise elements in the game.

In addition to the Likert scale questions, the survey respondents had an opportunity to provide open-ended comments regarding their experience of the game. When asked whether the game was "effective at conveying climate change in Lagos", one respondent commented that "*I think that for people with a basic knowledge and understanding of climate change will be able to understand it, but it might be harder for someone who doesn't have that understanding*." This is important feedback because it illustrates that prior exposure to climate change education may be necessary to be prepared to imagine such a radically different future.

Additional short answers are shown in Figure 9.

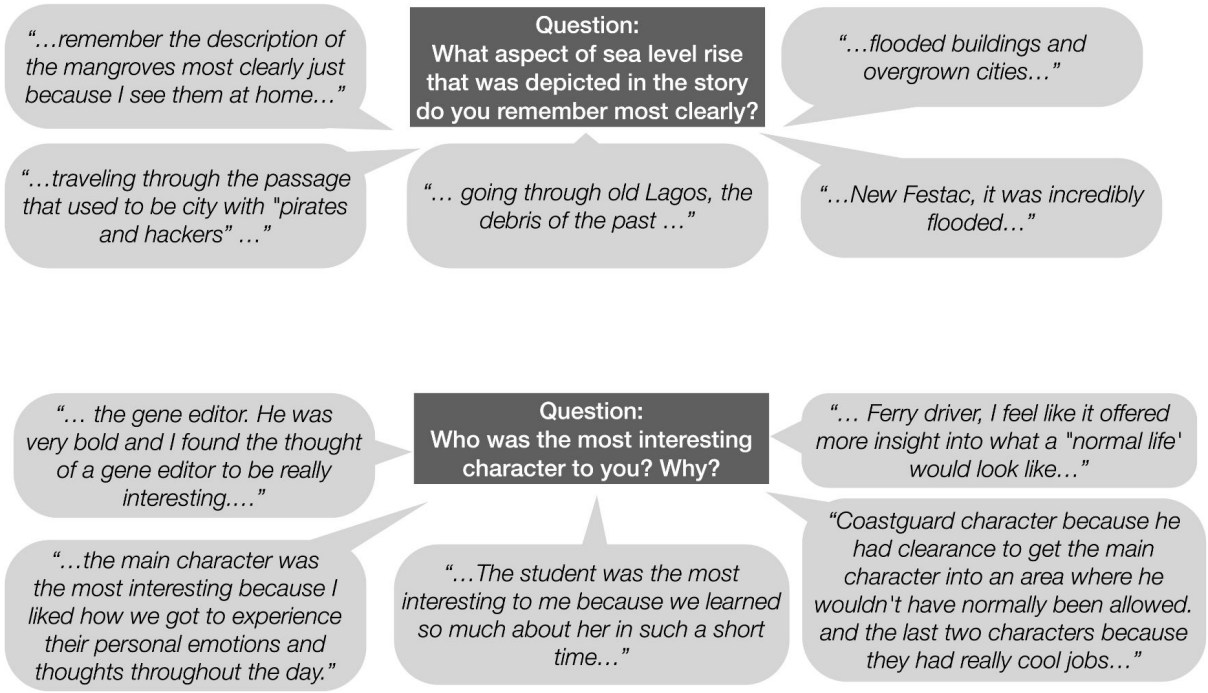

Figure 9. Short answers to open-ended questions about the Lagos2199 game.

5. Discussion

5.1 Sea level rise is highly visualizable

The fact that sea level rise will permanently change the coastline is self-evident. However, the fact that very specific places around the world will be changed in relatively well-understood geophysical ways remains an opportunity to glimpse the future remarkably clearly. In this case, we explored the changed coastline of Lagos, Nigeria. And to be clear, while we do not know the exact nature of coastline change, the ranges of expected sea level rise are constrained enough to get a reasonable idea of the ranges of human systems that might be impacted.

In Lagos2199, we use three meters of sea level rise as the amount of local change, which corresponds to a relatively successful strategy of mitigating carbon emissions in the 21st century, but not the most aggressive climate change mitigation path forward. The lowest projection of sea level rise associated with 2199 is 0.39 meters, and the highest is 9.7 meters (Sweet et al. 2017). While 0.39 would change the coastline much more modestly, 9.7 meters would be catastrophic and would likely only be reached with enormous, meltwater pulse events, similar to the deglaciation during the transition from the last glacial maximum to the present-day interglacial (Deschamps et al. 2012, Brendryen et al. 2020).

Regardless of the scenario that is used, the first order impact of any sea level rise scenario is inundating land, and changing the coastline. We have demonstrated that one can use multiple existing sea level rise simulations, and couple this with a direct analysis based on a digital elevation model of any location on Earth. Compared to most climate impacts, this is an unprecedented ability to peer into the future.

Other story-based scenarios of sea level rise from the fiction world have directly employed this feature of sea level rise to develop a future world. In the novel New York 2140, Kim Stanley Robinson

used the approach of identifying a new floodline (albeit improbable) in Manhattan (Billings 2017). Robinson said "*If Manhattan is inundated by 50 feet — an amount unlikely but not impossible — you can look at topographic maps from the U.S. Geological Survey and see what would be underwater and what would still be dry*."

There continues to exist considerable future opportunities for employing a method of detailed scenario analysis based on scientific projections of sea level rise. Likewise, as a method for teaching and education, such scenarios allow students to explore specific locations, which subsequently permits a more direct understanding of sea level rise consequences to society and ecosystems.

5.2 Futures methods for sea level rise education

A central finding in this work is that a story-based fictional game can improve the capacity of undergraduates to imagine a future radically unlike the present. While this is exciting, it is also consistent with other work that has employed story-based futures methods for educational purposes (Wu and Lee 2015, Abraham and Jayemanne 2017). Subsequent work could deepen the user experience of Lagos2199 in multiple ways. First, students can be shown a possible future via the existing Lagos 2199 game. Second, the game itself could be made more complex with additional branching storylines that delve into deeper treatments of aspects of the game. For example, each waypoint could include additional options for exploring how that location has changed due to sea level rise, and the coincident social-ecological change. Finally the students could be empowered to develop their own immersive scenarios following the same sea level rise-based methods detailed above.

It cannot be overstated how important it is to leverage multiple forms of media for engaging the world beyond academia to think more deeply about climate change. Education, especially with regard to climate change, must be perceived as more than a flow of information. Cultivating experiential, interactive opportunities that permit entangled emotional and intellectual engagement will be increasingly critical, especially as the anticipated future diverges ever more strongly from the past.

538 *5.3 Feedback between artistic process and scenario design*

539 The interplay between artistic creation and story development was neither linear nor isolated, but
540 rather multi-directional and iterative. The initial story design provided input to the character design, and
541 vice versa. As an example, the Nigerian Coast Guard Officer began as a character that would simply
542 allow the water taxi to explore the coastline of Lagos Bay. Then, as the broader scenario began to take
543 shape and the importance of the character took on different aspects, the design and artwork changed to
544 clarify the more sinister role the character served.

545 This iterative aspect is an important characteristic of scenario methods, particularly when trying
546 to tether them to humanistic and social aspects of the future (Raven and Elahi 2015). The importance of
547 design is also a critical feature for understanding how individual and group norms can be tacitly
548 embedded in perspectives of the future (Evans and Sommerville 2007). Moving forward, there exists a
549 significant opportunity to more deeply engage artistic co-design in the development of sea level rise-
550 based scenarios, and advance this effort more directly into design thinking curricula (Evans 2010).
551

552 # 6. Conclusions

553 Sea level rise will transform the coastlines of planet Earth in ways that are hard to imagine, within
554 the lifetimes of children born today. We document a method that takes a projected change in sea level
555 rise, explicitly models such changes on the coastline, and develops a novel scenario-based future, through
556 the creation of an immersive, educational game about climate change impacts. The resulting game,
557 Lagos2199, is then examined for educational efficacy among a group of undergraduate students who have
558 pre-existing knowledge about climate change impacts.

559 While Lagos2199 has individual utility for providing a unique vision of a sea level rise future in
560 Nigeria, we expect this work to have broader implications for the field of climate change education. First,
561 sea level rise projections are publicly and freely available, and based on the methodology we describe

562 herein, a baseline map can be developed for scenario analysis, anywhere in the world and with basic GIS
563 skills. Second, such a map is a fruitful starting point for story-based scenario design, particularly in the
564 future beyond 2100, when sea level rise impacts are likely to be highly consequential. Such stories can be
565 integrated into games, using free software and multimedia, to foster an immersive learning experience.
566 Third, and finally, such story-based games can provide an important complement to existing climate
567 change education programs, particularly those tasked with equipping students with a futures curriculum.
568 Indeed, providing the next generation of citizens with fluency in both climate change impacts and how
569 society will interact with such impacts, is necessary right now for effectively responding to accelerating
570 global change.
571

572 # 7. Availability of Lagos2199

573 The final game is freely available, and downloadable, at the link https://climate_futures.itch.io/lagos2199.
574 The game itself is released under a Creative Commons Attribution 4.0 International License (CC BY 4.0).
575 This license permits users to share Lagos2199, providing they provide attribution and may not use the
576 game for commercial purposes. The individual artwork and music have individual licenses from the
577 original creators, and are found in the Supplementary Information.
578

579 # 8. Data availability

580 All data that were used in this work is publicly available for educational and research use. The sea level
581 rise projections from Climate Central are available here https://sealevel.climatecentral.org/maps/. The
582 digital elevation model topography data are available here
583 https://portal.opentopography.org/datasetMetadata?otCollectionID=OT.042013.4326.1 . The open access
584 QuantumGIS Geographic Information System software was downloaded here:

https://qgis.org/en/site/forusers/download.html . The sources for the photographs and music are available in the respective Supplemental tables. The GNU Image Manipulation Program (GIMP) is available here https://www.gimp.org/ . The Twine software can be downloaded here: https://twinery.org/ .

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10. Supplementary information

A considerable amount of information is available in the Supplementary data for this work, including the Full text of the story, the 38 pieces of artwork in the game, a table of source material for the conceptual artwork with corresponding licenses, a table of music sources with corresponding licenses, and the original survey questionnaire.

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