The three reviewers made extremely useful and constructive observations about our manuscript. In the vast majority of the cases, we agreed with the reviewer's critiques and modified the paper accordingly. Our point by point response to each critique appears below in red text.

[* REVIEWS *]

SUBMISSION: 73
TITLE: The design and implementation of biological evolution as a video game mechanic.

----------------------- REVIEW 1 ---------------------
SUBMISSION: 73
TITLE: The design and implementation of biological evolution as a video game mechanic.
AUTHORS: Barrie Robison and Terence Soule

----------- Overall evaluation -----------
SCORE: 2 (accept)
----- TEXT:

1. However the sections, and especially the subsections related to the 4 evolutions characteristics are not well balanced (2.5 pages for the subsection related to selection and only a paragraph for the subsection related to time for example).

This is a result of selection being the focal component that unites the previous two (Variation and Inheritence). Nevertheless, we have attempted to make the longer sections more concise to better balance the manuscript.

2.   Some elements need to be clarified. In figure 1, we see the enemies become bigger when the fitness functions are turned on. The authors also say that this mutation depends on the strategies instituted by the player. It would be interesting to have another graph with the fitness function turned on, that shows different mutations to support this statement. Maybe this is what is shown in figure 2?

Indeed this is what is shown in figure 2. We have edited the manuscript to make this more clear.

3. Is the use of autocannon and chip shredders 2 distinct player strategies? This is not clear. The authors use the term "replicates" for the figure 3 for example. Do these refer to game sessions played by real players? How can they be replicates "of the exact same game conditions"?

We have clarified our definition of replicate (yes they are different game sessions, but no they are run autonomously after the player sets up their defenses). We have also clarified our rationale for running the replicates in this manner.

4. The authors talk about Darwin's Demons in the beginning of the paper but only use Project Hastur in the rest of the paper. Yet, the 4 evolutions characteristics are surely used in the first game as well. It would have been interesting to illustrate them with both of the games to prove the genericity of the proposed game mechanics.

The reviewer is correct. Darwin's Demons follows a very similar approach. We simply couldn't find a way to adequately include data from both games within the 10 page limit of the paper.

5. Finally, the authors argue that one must find a compromise between scientific accuracy and the fun and engagement in the game but no evidence is provided as to how much the scientific accuracy needs to be bent. This was probably tested in the Hastur and Darwin's Demons projects but not explained in this paper. How did the authors test this and obtain an "acceptable compromise"? Did the compromises lead to misunderstanding of evolution among the players or where they explained by the teachers or in the game to prevent this misunderstanding?

We acknowledge that the question of whether the games are effective learning tools is a critical question that is not addressed by this paper. The other reviewers expressed similar concerns. We have added a "Limitations" section to the paper to address this. The reality is that we have only just begun to collaborate with researchers in the learning sciences, and do not yet have the data to answer these questions. This is one of our main motivations for submitting to GALA and attending the conference.

6. I strongly encourage the authors to submit their game to the GALA SG competition.

We didn't really think our game would be eligible, since it was released a few years ago.

---------------------- REVIEW 2 ---------------------
SUBMISSION: 73
TITLE: The design and implementation of biological evolution as a video game mechanic.
AUTHORS: Barrie Robison and Terence Soule

----------- Overall evaluation -----------
SCORE: 0 (borderline paper)
----- TEXT:
In this paper the authors want to discuss the lessons learned from developing and releasing the 2017 "Darwin's demons" (a variant of Space Invaders) and 2019 "Project Hastur" (a Tower Defense) games, both launched on Steam, and that feature evolution as a core mechanic.

7. The author's claim to discuss the balance between realism and fun, but unfortunately what they mostly do is to use gameplay data from one of the games to show the dynamics of their in-game evolutionary models.

Yes, we have clarified the text to reflect our core objective, which was to demonstrate that evolutionary models can be used as a game mechanic, and how parameters of these models can be adjusted to increase playability.

8. The core of the paper is the discussion on four components of the evolutionary process: Variation, Inheritance, Selection, and Time. The authors compare real world evolution with their models in one of the games. Unfortunately there is nothing regarding learning outcomes.

See our response to this issue under Reviewer 1, point 5.

9. While discussing the balance and the choices between realism and fun as a topic would fits nicely to the GALA conference, this is not as clear in what regards the dynamics of the in-game evolutionary models.

Our objective was to share what we had learned as we implemented mathematical models of evolution as game mechanics. In particular, we were responding to the following in the "Serious Game Design" track from the CFP:

- Design and implementation of SGs mechanics (e.g., score, rewards, achievements, and related interfaces)

Still, we definitely recognize the need for research into learning outcomes as a critical next step with our games, as well as user testing related to engagement and playability.

10. It would be interesting to know what do players of the game learn about evolution after playing the game. Because a game can use realistic evolutionary models, and be fun, but if players learn nothing about the theme by playing the game, then we are not in the presence of a good serious game...

We agree. These experiments are important, and we have begun that process. See our response to this issue under Reviewer 1, point 5.

11. In the "bad examples" the authors refer to, the player intelligently designs its own creatures. In the two games the authors present, evolution is applied to the player's enemies. An interesting serious game design challenge would be to create a game like Spore™, Evolve™, or Pokemon™ but with realistic evolution...

We agree wholeheartedly! This comment is precisely why we applied to present at GALA. So many interesting ideas to discuss….

12. To conclude, the games described in this paper are not novel (the latest is from 2019), and the paper does include any reference to user tests and does not discuss the actual learning results of playing the game...

We address the lack of learning outcome data earlier in our response. With regard to the release dates of the games, our objective was to share what we had learned as we implemented

mathematical models of evolution as game mechanics. We do not intend this paper to be a delayed project description or release announcement for either of our games.

13. Some other notes...

    Because GALA readers need not be familiar with evolutionary biology technical terms, a succinct explanation of some terms (e.g. locus, matrix of recombination frequencies) would be nice. Also other terms (e.g: replicate) are not defined...

    An excellent suggestion. We have added explanatory text and definitions throughout.

    Variables (like e and u) should be written using math mode...

    We have italicized the two parameters.

    Reference to Steam should include the link as a footnote...

    We have put steam links for all games in the reference section.

    ----------------------- REVIEW 3 ---------------------
    SUBMISSION: 73
    TITLE: The design and implementation of biological evolution as a video game mechanic.
    AUTHORS: Barrie Robison and Terence Soule

    ----------- Overall evaluation -----------
    SCORE: 1 (weak accept)
    ----- TEXT:
    Overall, this paper contributes to the field of games and learning as it describes critical elements of serious games that are often overlooked, confounded, or discarded. I appreciate the scientific basis for the author's excellent descriptions and explanations of critical game elements such as time, etc.

14. While I appreciate this submission's novelty and potential contribution, I did not see an evaluation of any other authors' games of data (or summary of existing data) to exemplify the critical element they so eloquently portray in their well-written paper.
    Our objective was to share what we had learned as we implemented mathematical models of evolution as game mechanics. In particular, we were responding to the following in the "Serious Game Design" track from the CFP:

    - Design and implementation of SGs mechanics (e.g., score, rewards, achievements, and related interfaces)

    Still, we definitely recognize the need for research into learning outcomes as a critical next step with our games.