SIMOC – A hi-fidelity simulation of off-world, human habitation and bioregenerative life support as a platform for citizen scientists and virtual classrooms

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Abstract

The Scalable, Interactive Model of an Off-World Community (SIMOC) is an agent-based model, a simulation through which semi-autonomous agents interact and whose behavior, when allowed to unfold over a specified time, may exhibit non-linear, dynamic, and probabilistic behavior. Data was derived from plant physiology studies, the Baseline Values and Assumptions Document, and Environmental Control and Life Support Systems (ECLSS) modeling validated by Paragon Space Development Corporation. SIMOC approximates photosynthetic activated radiation (PAR), H2O, O2, and CO2 parameters with non-linear plant growth functions derived from a barley fodder experiment conducted at the University of Arizona's Biosphere 2. In addition to its research-grade simulation engine, SIMOC is a platform for education. SIMOC includes a fully developed, Next Generation Science Standards-aligned teacher-student curriculum for grades 5-8 and 9-14.

Users prepare a custom configuration of a human habitat on Mars. By selecting the duration of the mission, number of astronauts, stored food, crew quarters and greenhouse, type and quantity of plant species, and system for energy production and storage, students learn about the complexity and challenge of designing a long duration, off-world mission for which a balance between mechanical and plant-based life support is mission critical. As of June 2020 National Geographic is hosting SIMOC at the NGS Education Resource Library, a web-based repository of more than 4000 curricular assets for K-12+ with subjects including geography, biology, chemistry, anthropology, mathematics, physics, and space exploration.

This publication presents the results of a world-wide engagement of SIMOC, with specific examples of how SIMOC was integrated into virtual classrooms during the COVID pandemic for an iterative exploration of the scientific method.

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Nomenclature

Bioregeneration	=	plant-based recycling of air, water and production of food
ECLSS	=	Environmental Control and Life Suppport System
PAR	=	photosynthetic activated radiation
Physicochemical	=	machine-based recycling of air, water
SIMOC	=	Scalable, Interactive Model of an Off-World Community

I. Introduction

Figure 1 - SIMOC dashboard

Since the invention of powered flight and soon thereafter the rocket, humans have been fascinated with the potential of living away from our home planet. The Apollo era gave us a glimpse of both the challenges and reward of engaging in such an endeavor. Four decades later we are now preparing to return to the Moon and extend our reach to Mars. Both of these possibilities capture the imagination of people of all ages and present a powerful foundation for education, both in a formal classroom and online, through engagement of students and citizen scientists of all ages.

A Scalable, Interactive Model of an Off-World Community (SIMOC[7]) is a computer simulation through which semi-autonomous agents interact and whose behavior, when allowed to unfold over a specified time, exhibit non-linear, dynamic, and probabilistic behavior. Developed at the Arizona State University School of Earth and Space Exploration, Interplanetary Initiative, data was derived from plant physiology studies [1], the Baseline Values and Assumptions Document [2], and ECLSS modeling validated by Paragon Space Development Corporation. SIMOC approximates photosynthetic activated radiation (PAR), H2O, O2, and CO2 parameters with non-linear plant growth functions derived from a barley fodder experiment conducted at the University of Arizona Biosphere 2 [3]. In addition to its research-grade simulation engine, SIMOC is a platform for education. SIMOC includes a fully developed, Next Generation Science Standards-aligned teacher-student curriculum for grades 5-8 and 9-14.

[7] https://simoc.space

SIMOC users prepare a custom configuration of a human habitat on Mars. selecting the duration of the mission, number of astronauts, stored food, crew quarters and greenhouse, type and quantity of plant species, and system for energy production and storage. This engagement invokes learning about the complexity and challenge of designing a long duration, other-world mission for which a balance between mechanical and plant-based life support is mission critical. The tool offers helpful information to accompany all of the choices as well as graphs to help users visualize the data. Many other objectives are achieved as well. For instance, beyond the initial design of a habitat and use of SIMOC, users can use the data from the simulations to make adjustments to their designs and run additional simulations. Opportunities for further research (statistical analysis, machine learning) in order to understand the relationships between the many variables of SIMOC fulfill yet another objective. In addition to all of this, SIMOC allows users to become citizen scientists each time they run a simulation. In terms of pedagogical support, SIMOC exceeds its primary objective as it could easily be integrated into all academic subject areas as well as incorporate art and engineering in the design of the physical habitats.

While e-learning, distance learning, and virtual classrooms were already an integral part of education [4], the onslaught of the COVID-19 pandemic set in motion a complete transformation of learning and educational institutions world-wide. Classrooms that once integrated online research moved to rely entirely on a digital medium for all teacher and student interactions. This placed a heavy emphasis on computer software environments that enabled instructors to engage students in experiential learning. Without the possibility for face-to-face and hands-on activities, software that engages students in the formulation of a hypothesis, design of an experiment, and summary of the findings is imperative to the continued demonstration of the scientific method.

As of June 2020 National Geographic is hosting SIMOC at the its Education Resource Library[8], a web-based repository of more than 4000 curricular assets for K-12+ with subjects including geography, biology, chemistry, anthropology, mathematics, physics, and space exploration. SIMOC at Nat Geo grants educators, students, and citizen scientists around the world access to a Mars habitat simulator that engages students in the exploration of authentic NASA data from more than forty years of plant and human factor studies, coupled with a plant physiology study conducted at the renowned Biosphere 2 in early 2019 [3].

Written in the computer programming languages of Python and Javascript, SIMOC is hosted by Google Cloud Services for world-wide accessibility and easy of scalable deployment. User statistics were requested by Nation Geographic as a means to gage success in deployment, as follows. SIMOC sustains between 100-300 unique users per month with an average of 4:55 minutes duration and a very low 25% bounce rate (no interaction with a page before departing) where less than 40% is doing well. Users are principally from the United States, Canada, England, Germany, and several other countries, with an average 46% female and 54% male userbase.

This publication presents the results of an engagement of SIMOC by three instructors, two in the United States and one in Japan. We present specific examples, told in their own voices, how SIMOC was integrated into virtual and physical classrooms during the COVID pandemic as an iterative exploration of the scientific method. While this paper is focused on the experience of using SIMOC, it is intended to embolden the possibility of engaging eager students in experiential learning, both in the classroom and online. While SIMOC is focused on a long duration habitation of Mars, the strongest take-away is often a recognition of how our every day actions affect the biosphere in which we live. We hope this informs instructors around the world, encouraging the use of authentic data and the scientific method for all ages.

[8] https://www.nationalgeographic.org/education/resource-library/

II. The Classroom of Pete Barnes

Figure 2 - Students using SIMOC in the classroom of Peter Barnes

Our 2020-21 school year has been a roller coaster ride, as for most school districts across the country. We started the year with half of our students at a time in a hybrid model, then moved to all students in the classroom with desks six feet apart and masks worn; transitioned briefly to completely remote learning when our teacher absences reached critical levels, and then back to all students on campus. We still have students coming and going as they are quarantined, learning from home or logging in for Google Meet lessons. We are continually adjusting to change.

Using the SIMOC Mars habitat simulation in the classroom this year was different in that students were allowed to work together for only short periods of time (less than 15 minutes) with masks worn. Students are resilient and have adjusted to this reality, enjoying any time to work with others. We conducted several sessions with SIMOC as we geared up for a larger project about Mars colonization. I have 5th grade students, so I modified the experience to make it meaningful for ten and eleven year olds. We looked over the simulation together (mirroring on the classroom TV) and talked about some of the major factors in survival (oxygen, water, food, removal of CO2, plant growth, etc.). I showed them how to add and remove panels and how to set up their simulations. Students ran several simulations with different parameters and then reported their findings. I used a Google Form to collect information from students and to get them thinking about what is happening within the simulations.

Following the initial group effort, I encourage students to work out their own simulations, to give them agency over the process and to let them think through the consequences of different decisions. This is a nice introduction to a larger project we will start in a couple of weeks. After learning a little more about Earth and what makes ours a habitable planet, we will research Mars. Students will use Google Mars to choose landing locations for a Martian colony. They will plan materials needed for their mission and design colonies (first on grid paper in a blueprint style) then use their blueprints to make 3D models on Minecraft.edu. Students will present their finished colonies to classmates and will need to prove that their colonies will be safe and habitable using a set of parameters. I believe the SIMOC simulation got them thinking about some of these factors and will help them succeed on their final projects.

In general, students enjoyed using the SIMOC simulation. They understand the basic parameters that make a successful simulation, although we didn't have time to explore the more complicated data sources and parameters appropriate for older students. They were curious why certain plants grow very quickly (like radishes) and some seem relatively slowly. I told them I don't have all of the information to guide these answers, but they seemed excited about subsequently growing plants with their Minecraft colonies. I also only had limited knowledge to share about the ECLSS modules and how they work. Students asked for photographs and more information, which extends the learning process.

Students were not always clear if there are acceptable limits to the SIMOC variables, regarding some of their choices. *Why not max out everything? 10 ECLSS modules and 2,500 solar panels?* I asked students to think through the difficulty of getting large amounts of equipment and materials to Mars, but it seemed difficult for them to visualize these constraints within the SIMOC simulation.

Overall, this was a positive experience that engaged the students in the challenges of the human habitation of the Moon and Mars. It's not as easy as science fiction leads us to believe, and will take a concerted effort in the coming decades.

III. The Classroom of Gretchen Hollingsworth

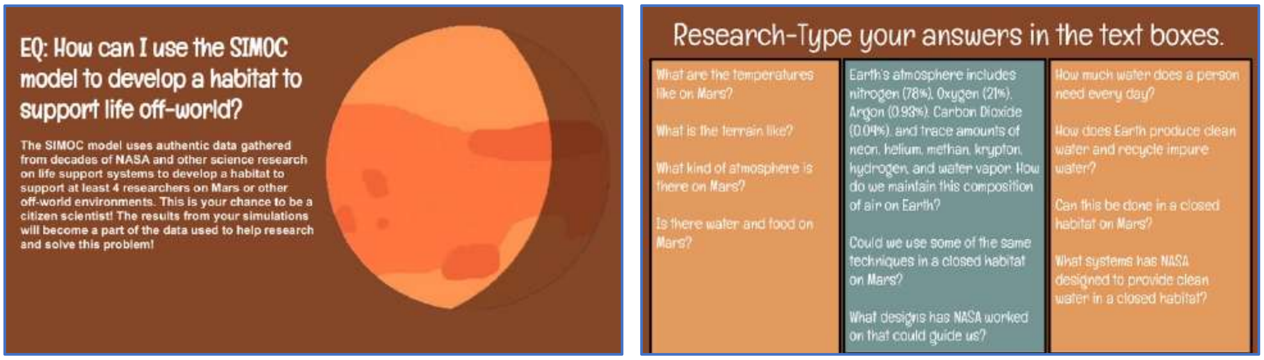

Figure 3 – Samples of a Mars habitat curriculum by Gretchen Hollingsworth

When COVID-19 turned the whole world upside down in the Winter of 2020, teachers around the world had to instantly redesign their entire curriculum to fit the needs of their students. During this time, I was fortunate enough to have the opportunity to beta test the SIMOC habitat simulator with my students. I had a decision to make: *Do I "survive" the rest of the school year using digital worksheets and Google Meet lectures, or do I take a risk and integrate this cool tool in our learning?* The fact is, I love integrating technology into my lessons, so my students were well prepared for at-home learning. We needed a new challenge and the SIMOC model was a perfect fit for us!

At that time I was teaching 6th and 7th grade science. In Georgia, 6th grade focuses primarily on Earth and Space Science while the 7th grade content is Life Science. I was so excited because I could easily connect the design of a human habitat on Mars to the standards of both grade levels. I took advantage of the already developed SIMOC curricula and adapted it for my online learners. I basically condensed a good deal of the information in a Google Slideshow for my students, so they could independently progress through the simulation and activities on their own. Ultimately they were expected to research the conditions on Mars, consider the necessities for survival, design a habitat (2D or 3D), run the simulations multiple times adjusting as needed, and reflect on their findings.

I made specific connections to the previous learning we had done on topics such as overpopulation, the need for sustainable solutions for pollution, renewable vs. nonrenewable resources, and the requirements to sustain life with connections to the atmosphere on Mars vs. the atmosphere on Earth. I engaged them in thinking about what would be needed to realistically live on Mars. We talked about all of the population and sustainability problems we explored throughout the year and identified that one solution could be to inhabit Mars. From that point forward, students were researching, designing a habitat, and testing their ideas. They had to consider the cost to transport materials to Mars, how many humans could be supported, what would they grow to eat, how much space they would need, and also account for the mental health of the inhabitants among other things. This was much more beneficial than a Google Meet lecture and a digital worksheet! This was authentic citizen science because the data from their simulations could be used to benefit the collective good, and the students loved it! They benefited so much from researching the problem, exploring solutions, designing a habitat, and testing it out in SIMOC. They adjusted their designs and saw the results in the simulation.

Overall, I found the use of SIMOC with my students during digital learning to be incredibly beneficial and a true problem solving activity that encouraged students to see how our choices now can result in challenging decisions in the future. *How amazing is it that we could pull this off during digital learning at the end of the school year in a worldwide pandemic?*

Fast forward to Winter of 2021. I now teach 8th grade Physical Science and High School Physical Science at a new school in our system. Yet again, SIMOC is easily integrated into my curriculum. This time I was able to use SIMOC with students both in person and online, as our students have the choice to participate through digital or in-person learning. I reach all of them at the same time by using Google Meet to broadcast our classroom to the students at home. This year I decided to take a different approach.

Figure 4 - NASA Perseverance Mars rover

Of course I still connected the same concepts mentioned above because these are ongoing issues no matter their grade level; however, I chose to have students discuss atmospheric density and the behavior of gases on Mars, as my High School Physical Science students were learning about ideal gas laws at the time. This was a new way for me to engage the students in the design of the perfect Mars habitat as they now had a more developed understanding of the challenges. In addition to this, with Mars Perseverance landing on February 18th, this was the perfect time to discuss how our research and experiments now help to provide opportunities for humans in the future. In fact, Mars Perseverance was what I used to first engage the students, and we talked about privately funded aerospace programs such as SpaceX and Blue Origin. We then we transitioned into discussions of the challenges not just with space travel but with creating a sustainable habitat on Mars. My favorite part of the discussion was when we talked about how this work is for the greater good and how sometimes the work we do now is not necessarily for our own benefit but to benefit others, and thanks to those before us who laid the groundwork to provide these opportunities for us now. So although we haven't gone through the whole process of researching and designing a habitat yet this year, we have used our prior knowledge to make connections and run simulations to celebrate Mars Perseverance and learn about how it takes a collective effort to make progress!

Thank you for this amazing resource and the opportunity to share our experiences! I teach some of the same students this year that I had last year, and they were thrilled when I pulled up our examples from last year that are featured on the SIMOC site. They were so happy and proud to show their new classmates what they had designed and tested! Below are some of my favorite quotes from running our simulations this year. Students were excitedly announcing their progress (quotes below), and it warmed my heart to see them so excited about science! They were begging to take turns to come up to the board and run a simulation for the class. It was awesome to do this in person as opposed to just virtually last year. I could actually see the excitement in their faces!

"Yay! My person survived 99 days and 23 hours!"

"We've been on Mars for a year!"

"I don't have much oxygen left, so I need to figure that out!"

"My simulation is weird. I have 10 people in a small space for 365 days. They are dying fast. Actually they are fully dead now. They lasted 72 days."

"Oooh! Their energy is going up! Look at that!"

"Oh no, there's not enough power! It must be nighttime."

"Their food! Oh no! But I did the math!"

"It's very hard to keep people alive on Mars! It is not habitable if you are talking about long periods of time."

IV. The Classroom of Michael A. Pope

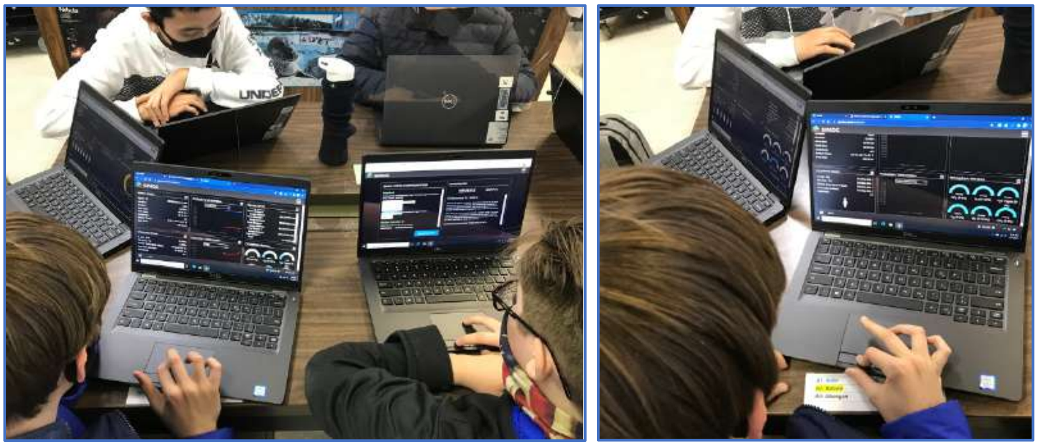

Figure 5 - Students using SIMOC in the classroom of Michael Pope

The year is 2020 blurring into 2021 and teaching as we know it has changed for now, perhaps forever. The demand to use technology and data has permeated past the filters of the monthly teacher faculty meetings and right into the classroom itself. With the Covid pandemic separating students from students and teachers from students, how can a STEM teacher find ways to connect during a time of literally a great disconnect? I check my emails and my eye catches sight of an email from Tyson Brown and my mind drifts to a past daydream of the red planet.

What kind of, "Good Trouble" I can get into with this interactive digital resource?

This year I am teaching 7th grade science. While the space portion of our studies is limited, Mars does pop up. The difference between this interactive, web based program and what I am currently using is just that. The program gives students the feel of, while conducting activities, being a real scientist or a science team monitoring—or actually living on the planet Mars. This connects well as an extension idea with the current curriculum activity *Continue Your Exploration* activity called "Destination Mars." Especially now with the Mars Rover Perseverance set to land in less than a week.

Since my move from mathematics back to science this semester, most of my time has been spent learning the ins and outs of the new curriculum and the district expectations. Unfortunately, SIMOC was not the center piece that I had hoped for but served more as a way to support the core concept and the excitement around the Mars rover landing.

Presently, I have a small, core group of students who are working with the program, excited to make the connection to the current world-wide event next week. I think that after I get my foundation in the new curriculum I will bring in more students and then a class or two. Next year, I can see this being a portion of the third quarter lesson and all students can be involved.

When I initially previewed the program I liked the data streams and simulations it provided. It was what I was used to using and similar to the GAVRT program my students and I used many years ago. The student testing group was giddy with excitement. After I explained more about the data collection protocols and potential, they got even more excited. They were discussing the potential to have larger group sizes with the program and other food options.

The potential is definitely there and if I keep playing with it and asking more questions to my students, I am sure more constructive ideas will be forthcoming. The student take-away would have to be that science is fun and the research does not have to be boring and dull. The face of education has changed and the venue may be fluid, but one thing remains the same—students want to learn. Regardless of the fear of a pandemic and removal of the human connection via distance learning nothing can stop education. As long as there is a student hungry to explore and a longing thirst for knowledge, teachers will serve up a meal in the digital or analog world.

SIMOC proved to be a great tool in my classroom.

V. Constructive Feedback and Continued Development

The SIMOC development team maintains a product roadmap that aims to continually improve the underlying research engine and web-based user experience. SIMOC is in its fourth phase of development whereby the data display panels have been consolidated and redesigned for improved readability and the runtime performance improve, given large classrooms noting slow performance, even stalls in simulation runs late in 2020 and early 2021. The next improvement introduces crop rotation schedules and the addition of nutritional value for each food type in addition to carbon dioxide sequestration. Future phases of development will introduce entropy as an additional source of non-linear behavior and ultimately a source for variation in the behavior of agents, even the capacity for agent (a square meter of plants) and systems (an entire greenhouse) failure.

In addition, the three instructors who participated in this paper, Peter, Gretchen, and Michael each offer constructive feedback for SIMOC, as follows.

Peter writes, "While the simulation is appropriate for fifth graders, elementary and probably middle school students could benefit from a more structured or feedback driven setup. For example, we use simulations on the site Learning Gizmos[9], a paid site with high quality simulations in different science disciplines. The data is not generally as complex as SIMOC, but the concept is similar. I typically give students time to explore the Gizmo on their own, but then the site has structured activities that walk the students through the simulation with questions or prompts such as *What happened? Why?*

Gretchen writes, "I've [used] Nat Geo's Interactive Map Maker[10] with my students in the past. While the tool was fun and useful, I feel it was not as user friendly as SIMOC. I did ask my students for improvement suggestions for SIMOC and they proposed more options for [habitat] designs … more food choices, more choices overall … referencing the plans for more location options beyond Mars, such as on other planets or Earth's Moon. Some students suggested making the dashboard more gamified with graphics that reflect the options available and/or animations during the simulation to make the tool more appealing to younger users."

Michael writes, "The integration of online learning, real-world application and inquiry based was what I would focus on with the added information. I did share this with multiple teacher networks both national and international so the program has a definite global reach. If [SIMOC] could build in a collaboration component, then it would have made the jump to online global collaboration."

The SIMOC team has received this feedback and will incorporate into Phase V development plans.

VI. Conclusion

The SIMOC web-based interface to the Mars habitat simulation engine engages students of grades 5-8 and 9-14 in a unique, experience of the scientific method. Through design, test, and review of various habitat designs that incorporate human, plant, and mechanical agents, virtual and classroom students and citizen scientists alike are able to participate in an important aspect of the human exploration of the solar system and beyond. In this paper, three classroom instructors integrated SIMOC into their curriculum and shared the results through the student experiences.

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[9] https://www.explorelearning.com
[10] https://mapmaker.nationalgeographic.org/

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