Starchitect

The Educator's Guide

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N.B. This document isn't a curriculum, just (1) an introduction to the game in the context of classroom use, and (2) a good faith effort at making connections between the game and science standards. If find that this is of use for your class, or have suggestions for making useful, feel free to let me know at the email above.

Contents

Introduction

Overview: *Starchitect* is an online game designed to introduce players to the basic concepts of stellar and planetary evolution. Players can form their own star, build both giant and terrestrial planets, add moons, attempt to initiate life, and observe as the system evolves in scaled real time (a million years per minute). In the end, the system will meet a fate determined by the mass of the star: either the planets will be overwhelmed by the envelope of the red giant, or be obliterated by the searing heat and gamma ray blast of a supernova.

The game is designed to be played over time, rather than in one sitting, along the lines of "Farmville." It takes several days of elapsed time to create an inhabited world, and star lifetimes may range from minutes to weeks. As a result, it may be more suitable as an extra credit, out-of-school activity, rather than something to be played in a computer lab. There is a built-in reports system (see below) that lets players email their progress to their instructor..

Learning Goals: Depending on the amount of time spent in the game, students can discover:

- That stars are born and die, and their life cycle is controlled by their initial mass;
- That the structure of the solar system is influenced by both the gravity of the sun and the planets themselves: planets and moons placed too close together will not be stable;
- That solar systems have "habitable zones", inside which planets can support life, however the location of these zones depends on the type of star and its corresponding luminosity;
- A sense of the time scales for the evolution of life and the solar system in general (due to the consistent time scale of the game of 1 million years to the minute)
- A sense of the distance and length scales of the solar system, through the use of the different display modes and the "*Sizemology*" minigame;
- That various events can interfere with the progress of life, including stellar encounters, supernovae, asteroid impacts, and "gamma ray bursters".

Game Play: The game framework uses the "sporadic play" model typical of some Facebook games and incorporates a number of "Feats" that both unlock features and guide players towards specific learning goals.

How Long Will This Take? It's important to note that this is not a quick game that can be played in a single session. It will take at least several days to successfully generate life on a planet. However, it does not require a significant amount of actual playing time (a few minutes a day is sufficient).

Progress Reports: Players can optionally email reports to an instructor showing their progress (in the event that the game is being used for extra credit).

Target Age: The learning goals for the activity map most closely to late middle school, early high school standards concerning the structure and evolution of the solar system and galaxy. However the game has been used for introductory college astronomy classes as well.

Suggested Use: Given the time scales of the game, this is probably most appropriate as an at-home assignment that spans the time when the matching concepts will be covered in class.

Credits, Funding: The game was designed by James Harold, Dean Hines, and Evaldas Vidugiris at the Space Science Institute (www.spacescience.org). The project was funded through grants from the National Science Foundation and NASA. Its prototype, *MyStar*, was developed with funding from the Space Telescope Science Institute (STScI) and the Space Science Institute's (SSI's) "*Alien Earths*" project.

Key Game Elements

Persistency: the game runs on a server in the background so that systems can evolve while the player is offline.

Time Scales: Events occur on a timescale of one million years per minute. Giant worlds can be built in a few minutes; terrestrial worlds a few minutes after that. Single cell life can arise within an hour, but complex life can require several hours. Star lifetimes can range from seconds (for supergiants) to weeks (for sun-like stars).

Energy: Many tasks (creating planets, triggering life) require energy units. These automatically replenish over time. The maximum energy a player can accumulate can be increased through gameplay.

Feats: These are specific tasks that can earn players points, unlock features, etc. Some feats simply introduce game elements to the players, while others are focused on specific content goals (e.g., "create a solar system that looks like ours").

Customization: Planets can be patterned and colored. The color pallets and designs are a function of the planet type and its distance from the sun (e.g., distant giant worlds will be shades of methane blue).

Relation to Standards and Benchmarks: the structure of the game lets us directly address stellar lifecycles; their dependence on initial mass; their relative timescales; the role of gravity; as well as some conditions relating to life including both galactic and stellar "habitable zones." See later sections for more information on connecting to standards.

Ready? Set? Play!

The game can be played either at www.starchitect.net, or through Facebook (https://www.facebook.com/StarchitectGame). There are three ways to sign in to the game:

- Using a Facebook login
- Using a login unique to *Starchitect* (particularly useful for children under 13 or for classrooms)
- As a guest, with no sign-in.

If the Guest option is chosen, the game will store the user id on the local computer. This means that only one player can use that computer, and they will not be able to continue the game from another location.

The Tutorial

New players will be guided through a short tutorial, during which they will create their first star and first planet.

Feats and Fast Feats

The game has over 100 Feats. Recommended Feats show up as icons at the upper left of the screen. "Fast Feats" are simple things that can be done any time, often related to learning something about how the game works (e.g., "Animate a system"). See the later sections of this document for lists a the more commonly achieved feats and how they map to education standards.

Mini-Games

Starchitect includes several minigames that focus on specific topics, and serve to unlock other elements of the game. These include:

- Sizemology: this is a scale game, in in which players are asked to adjust the scale of two objects until they are at the correct relative sizes. This game unlocks the ability to “cheat” at scales, making planets extremely large so that they can be seen on the scale of the solar system (the typical way solar systems are visualized).
- Stability: this is a “many body” gravity simulator. In this minigame players can actually watch the effects of a large planet on the orbit of another (the main game simply performs a mathematical test and ejects planets that are deemed unstable.) This game can also be found online and as an app at www.scigames.org
- Star Maze: this is essentially a simple maze game, but it embeds information about different star types, as well as various facts about stars.
- Extreme Seasons: an introduction to the “reason for seasons” by comparing Earth with Uranus, the planet with the most extreme axial tilt in the solar system.

Creating Stars

A key learning goal of the game is that stars have life cycles which are determined primarily by their initial mass. Players can choose the mass of their star: large stars will supernova quickly; small stars will live long enough to support planets.

Creating Planets and Moons

Opportunities to build planets come in specific windows during the life of the star. Giant worlds come first: these can’t support life, but they can help shield planets from asteroids and comets that could lead to extinction events. Moons come next, since they are often formed over material that didn’t collapse into the main planet. There is a hidden Feat here: if a player tries to create a moon too close the plane it will be unable to form, and a ring system will result. This minimum distance is called the “Roche Limit”: a little research can demonstrate that Saturn’s rings are inside its Roche Limit.

Terrestrial planets come next: these can support life, but only if they’re placed in the star’s habitable zone, the location of which depends on the star’s mass. Note that the game is structured in a way that prevents you from adding a moon to a terrestrial planet. This is by design: our moon (the only significant moon of the inner planets) formed in an entirely different fashion than the giant planet moons. One favored scenario is that a sister planet was forming at a Lagrange point, 60 degrees ahead or behind Earth in the same orbit. This planet destabilized and collided with Earth, creating a ring of debris that formed the Moon. It’s possible to do this in the game as well.

Note that each time a planet or moon is added, the game checks for stability: objects that are too close will destabilize and one will be ejected. This means that if a player places a giant world too close to the sun they may be unable to place a terrestrial planet there later on. This is relevant to the real-life search for habitable worlds in other solar systems: if a giant world is already in the habitable zone we’re unlikely to find an Earthlike planet there as well.

Life

The window for generating life only appears after the “heavy bombardment period” for the system has ended; prior to that the planets are regularly sterilized by impacts. Life is broken up in to multiple stages, and each must be successfully completed in turn. The difficulty of each stage is modeled after our understanding of the evolution of life on Earth: simple life appeared very early on, immediately (on geologic time scales) after the end of the bombardment. The transition to multi-cellular life took much longer, and which point life evolved rapidly.

Nothing lasts forever

Eventually stars will reach end of life, with the ultimate fate depending on the stars' initial mass: red dwarfs will last essentially forever, while higher mass stars have progressively shorter lives. Those stars will eventually either move through a red giant phase and collapse to a white dwarf, or supernova. These final stages occur very rapidly compared to the rest of the stars' evolution, but players can always go backwards in time to see them again.

Where to Build

The galaxy, like solar systems, has "habitable zones". Some areas lack the metals necessary to build stars and planets. Others are so dense with stars that the odds of local supernovas, gamma rays bursters, or simply near collisions, will make it difficult for life to form and survive.

Sending Progress Reports

If you're using this for extra credit and want students to be able to submit progress reports, do the following:

1) Create a group (in the Friends tab). Give it a unique name, and let your students know what it is so they can join.
2) Enter your email address in Settings (the gear icon at the upper right).
3) You students should now be able to send you a report by opening the Friends tab and selecting the Option button.

Questions?

If you have any comments, questions, or suggestions, feel free to contact James Harold at harold@spacescience.org. Thanks!

Key Feats and Content Notes

This is a list of some of the more commonly achieved Feats, and the science content that relates to them. The Feats are listed roughly in the frequency with which they're accomplished (the top ones are most common, the bottom ones least common).

Feat Name	Feat description	Content notes
Tutored	Complete tutorial (create star, create first planet).	Stars come in different types/sizes/colors (only two smaller types are initially available). Giant worlds form relatively quickly -- within two million years (two minutes of game time).
Twins **See Ya!**	Place two giant planets in one system. Destabilize a planet or moon with another one.	If planets are placed too close together, one will be ejected from the system. This is a first introduction to the role of gravity in creating stable or unstable orbits.
Move your Bodies	Animate a system	Planets are animated according to Kepler's laws: the orbital periods of inner vs. outer planets can be discussed. If moons have been created, the orbital periods for different mass planets can also be discussed. Note that all orbits in the game are circular. While it's possible in the real world to have orbits that are both stable and significantly non-circular, it's very much the exception. Pluto is an example of this, and is stabilized by its resonance with Neptune.
Mooning	Create a moon	Note that moons can only be created directly for giant worlds. Earth is unique in being an inner terrestrial planet with a significant moon (Mars' moons are very small and are probably captured asteroids).

Solid	Create a terrestrial planet	According to current models, terrestrial planets form later than giant worlds. It takes longer for the rocky debris and "planetesimals" to merge than for the giant worlds to accrete gas.
Almost **If You Like It**	Prevent a moon or planet from forming by placing it too close to its parent. Create rings around a giant planet	While there are different ways for rings to form, Saturn's dramatic rings exist inside the Roche Limit, the point at which gravitational tidal forces would prevent particles from coalescing into a moon. It's unclear if Saturn's rings are young (less than a few hundred million years) or old: if they're young, one possibility is that a small moon was destabilized, moving closer to Saturn and breaking up as it went.
That Will Do	Place a terrestrial world in a habitable zone	The habitable, or "Goldilocks" zone is the distance from the sun where liquid water could exist on a planet. Since life as we know it needs liquid water, this has historically been a key concept for discussions of habitable planets. The discovery of deep ocean vent life on Earth has broadened the concept of habitability (see discussions of Europa and Enceladus), but the habitable zone is still core to the search for extrasolar life. Note that the habitable zone depends on the luminosity of the star, so it's in a different location for each star type.
Scale 3 Stars **Upscaled** **Bigger is Better**	Get 3 stars in the 'Sizemology' minigame Get at least one star on each 'Sizemology' minigame level Change the scale of a system	The "Sizemology" minigame challenges players to change the size of various objects until they are at the correct relative scale (beginning with familiar objects, then moving to planetary ones). Once a player has succeeded with Sizemology they can change the scale of their solar system, making the planets artificially large. This will allow them to make solar systems that look the way they do in most illustrations. The hope is that, by making them work for that ability, they will be more aware of just how artificial those images are.
Centered (and other end stage feats)	Bring a system to its end stage in the "Galactic Bulge."	The point of bringing a star to end-of-life is simply to note how long this takes, and what the final stages are. These vary by star type. Note that red dwarfs last effectively forever: models suggest that their lifetimes exceed the age of the universe.

The Single Life (and other life feats)	Start simple single celled organisms on a planet	The model for life in Starchitect is extremely simplistic. The most important things to note are the relative time scales for different types of life. The game is structure to approximately replicate how long these stages took on Earth. In a nutshell, very simple life occurred almost immediately (in geologic terms) after the heavy bombardment of asteroids ended. It took a very long time after that to make the step to multi-celled life, but once that occurred everything moved very quickly. In addition, less-than-ideal planets may allow simple life, but not complex, reflecting the idea that you might, for instance, be able to have subsurface, microscopic life in very inhospitable environments (this is the most likely scenario for Mars, Europa, and Enceladus, if any life exists there at all).
Protector	Have a single giant planet absorb 50 small impacts.	Extinction events on habitable worlds can be mitigated by placing large giant planets in the system. We've seen concrete evidence of Jupiter "vacuuming" space for us in the case of Shoemaker-Levy and other impacts.
Mind the Gap	Create gaps in the rings of a giant planet.	Moons create resonances in specific orbits: particles in those orbits are regularly kicked by the moon's gravity until they eventually are moved out of that orbit. This is one way gaps are generated in ring systems, and *Starchitect* replicates this. So to create interesting rings patterns, the player needs to add multiple moons.
Outer Home **Inner Home** **Full House**	Complete our outer solar system. Complete our inner solar system Complete a solar system just like ours.	These are straightforward (if difficult) feats: the player will need to look up the masses and locations of the relevant planets, and create a system to mimic ours. They will also need to have leveled up to a point where they have enough energy to create this many planets.
Well Seasoned	Complete the "Extreme Seasons" minigame.	This simple minigame introduces the "reason for seasons" using Uranus as a comparison: with an axis tilted completely over by 90 degrees, Uranus has the most extreme seasons of any planet in the solar system.

Links to NGSS Crosscutting Concepts and Disciplinary Core Ideas

Starchtect can be used as a context for exploring a variety of NGSS topics. Below we list some Crosscutting Concepts and Disciplinary Core Ideas from NGSS, highlighting those that connect well to the game.

The italicized text is taken (and sometimes lightly edited) from:

> A Framework for K-12 Science Education:
> Practices, Crosscutting Concepts, and Core Ideas (2012)
> http://www.nap.edu/catalog/13165/a-framework-for-k-12-science-education-practices-crosscutting-concepts

Crosscutting Concept	*Starchitect* connection points
Patterns. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.	*Starchitect* will eject planets based on gravitational effects and resonances. This means that the general structure and spacing between planets can be compared to those in our own solar system. *Starchitect* also assumes a taxonomy of planet types (giant worlds and their moons, versus terrestrial worlds). Formation times and sizes are all taken from current science, which means it can be used as a context for discussing the differences between planetary types, and how scientists organize them.
Cause and effect: Mechanism and Prediction	*Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.* As a simulation, much of what occurs in *Starchitect* is the result of prior actions by the player. Choice of the star mass determines its life cycle; the location of a planet determines

	its color palette (e.g., methane ice blues for distant giant worlds; blues and whites in the habitable zone; reds and browns near the star). Placement of terrestrial worlds in or out of the habitable zone controls their ability to produce life.
Scale, proportion, and quantity.	*In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.* Both time and length scales are key elements of *Starchitect*. System time unfolds for the player at one million years per minute. That means that relative times for various events can be compared: time to form giant worlds, time to form terrestrial worlds, time to evolve life. Comparing these scales with the lifetime of various star types can lead to a variety of conclusions: for instance ,which stars are most likely to host inhabited worlds, and which stars would be expected to be the most common in the night sky. *Starchitect* also explicitly address common misconceptions about length scales in solar systems by defaulting to correct relative scales between planet sizes and distances. The embedded "*Sizemology*" minigame compares the relative sizes of a number of astronomical objects. Success allows players to unlock the ability to alter the system's size scales to create images of their solar system similar to the usual, incorrectly scaled images seen in the press.
Systems and system models.	*Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.* The game itself represents a model of course. Students can discuss what elements of the model are accurate, and/or predictive. For instance, the game animates the planets correctly, but their orbits are constrained to circles. *Starchitect* could be used to predict the existence of solar eclipses, but the circular, two dimensional orbits would imply a much greater frequency.
Energy and matter: Flows, cycles, and conservation.	*Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.*

	While Starchitect only introduces the concept of habitable zones, the can be used as the starting point of a discussion of energy flows into and out of planets. This can include the effects of greenhouse gases (which trap heat, altering the net balance: compare Mars, Earth, and Venus), or discussions of non-stellar energy sources for planets, such as heat from a planet's core (see Earth's deep ocean vent life), or from gravitational tidal effects in giant world systems (e.g., Europa and Enceladus).
Stability and change.	*For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.* An early lesson of *Starchitect* is that planets must be positioned far enough apart that their mutual gravity will not destabilize each other. The *Stability* minigame makes this more explicit: students can see the effects of large planets on the orbits of others. This plays an enormous role in the long term stability of the solar system, which is critical for the evolution of life. The current positions of the planets is not coincidental: they represent a long term, gravitationally stable system. Early in the solar system this was not true, and it's believed that a rearrangement of the outer planets led to a second "heavy bombardment" of Earth. In addition, stellar lifetimes have an obviously important role to play in the evolution of life. Players who progress far enough to create larger mass stars will realize they simply don't have enough time to evolve life. This is why some researchers are interested in finding life around red dwarf stars: they life much longer than even our star, and could provide that much more time for life to evolve.

Disciplinary Core Idea	Connection points in Starchitect
ESS1.A: THE UNIVERSE AND ITS STARS ***What is the universe, and what goes on in stars?***	*The sun is but one of a vast number of stars in the Milky Way galaxy, which is one of a vast number of galaxies in the universe.* *The star called the sun is changing and will burn out over a life span of approximately 10 billion years.*
SS1.B: EARTH AND THE SOLAR SYSTEM ***What are the predictable patterns caused by Earth's movement in the solar system?***	*Solar system consists of a star and other objects —including planets and their moons—that are held in orbit around the star by its gravitational pull on them.* *Planets and moons have predictable patterns of movement. These patterns, which are explainable by gravitational forces and conservation laws, in turn explain many large-scale phenomena observed on Earth.* *Planetary motions around the sun can be predicted using Kepler's three empirical laws, which can be explained based on Newton's theory of gravity. These orbits may also change somewhat due to the gravitational effects from, or collisions with, other bodies.* *Gravity holds Earth in orbit around the sun, and it holds the moon in orbit around Earth. The moon's and sun's positions relative to Earth cause lunar and solar eclipses to occur. The moon's monthly orbit around Earth, the relative positions of the sun, the moon, and the observer and the fact that it shines by reflected sunlight explain the observed phases of the moon.* *Earth's spin axis is tilted relative to the plane of its orbit, and the seasons are a result of that tilt. Seasonal variations in that intensity are greatest at the poles.*
PS2.A: FORCES AND MOTION ***How can one predict an object's continued motion, changes in motion, or stability?***	*An understanding of the forces between objects is important for describing how their motions change, as well as for predicting stability or instability in systems at any scale.* *Objects with mass are sources of gravitational fields and are affected by the gravitational*

and ***PS2.B: TYPES OF INTERACTIONS*** ***What underlying forces explain the variety of interactions observed?***	*fields of all other objects with mass. Gravitational forces are always attractive. Newton's law of universal gravitation provides the mathematical model to describe and predict the effects of gravitational forces between distant objects. These long-range gravitational interactions govern the evolution and maintenance of large-scale structures in the universe (e.g., the solar system, galaxies) and the patterns of motion within them.* Much of *Starchitect* serves as a demonstration of the role of gravity as a force between objects in the solar system. The *Stability* minigame is a particularly effective "sandbox" game for exploring these concepts, including Newton's third law (for any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first but in the opposite direction). This minigame is also available as a standalone activity and mobile app at *www.scigames.org*.
PS2.C: STABILITY AND INSTABILITY IN PHYSICAL SYSTEMS ***Why are some physical systems more stable than others?***	*Events and processes in a system typically involve multiple interactions occurring simultaneously or in sequence. The system's stability or instability and its rate of evolution depend on the balance or imbalance among these multiple effects.* *A system can be changing but have a stable repeating cycle of changes, with regular patterns of change that allow predictions about the system's future (e.g., Earth orbiting the sun).* *Viewed at a given scale, stable systems may appear static or dynamic.* *When a system has a great number of component pieces, one may not be able to predict much about its precise future.* As previously mentioned, solar system dynamics is an excellent example of the importance of stability. In the case of *Starchitect* this is reduced to the role of a single force, gravity. Students can discuss why planets that are too close together are unstable, as well as the role of tidal forces for moons, which can be seen when formation of a moon fails in the game, resulting in rings. The rings themselves will also display gaps based on resonances with other moons in the system, another form of gravitationally driven instability.

Summary of the “Universe” standards from the 2061 Benchmarks

From: http://www.project2061.org/publications/bsl/online/index.php?chapter=4

By the end of the 2nd grade, students should know that

- There are more stars in the sky than anyone can easily count, but they are not scattered evenly, and they are not all the same in brightness or color. 4A/P1
- The sun can be seen only in the daytime, but the moon can be seen sometimes at night and sometimes during the day. The sun, moon, and stars all appear to move slowly across the sky. 4A/P2
- The moon looks a little different every day but looks the same again about every four weeks. 4A/P3

By the end of the 5th grade, students should know that

- The patterns of stars in the sky stay the same, although they appear to move across the sky nightly, and different stars can be seen in different seasons. 4A/E1
- Telescopes magnify the appearance of some distant objects in the sky, including the moon and the planets. The number of stars that can be seen through telescopes is dramatically greater than can be seen by the unaided eye. 4A/E2
- Planets change their positions against the background of stars. 4A/E3
- The earth is one of several planets that orbit the sun, and the moon orbits around the earth. 4A/E4
- Stars are like the sun, some being smaller and some larger, but so far away that they look like points of light. 4A/E5
- A large light source at a great distance looks like a small light source that is much closer. 4A/E6** (BSL)

By the end of the 8th grade, students should know that

- The sun is a medium-sized star located near the edge of a disc-shaped galaxy of stars, part of which can be seen as a glowing band of light that spans the sky on a very clear night. 4A/M1a
- The universe contains many billions of galaxies, and each galaxy contains many billions of stars. To the naked eye, even the closest of these galaxies is no more than a dim, fuzzy spot. 4A/M1bc
- The sun is many thousands of times closer to the earth than any other star. Light from the sun takes a few minutes to reach the earth, but light from the next nearest star takes a few years to arrive. The trip to that star would take the fastest rocket thousands of years. 4A/M2abc
- Some distant galaxies are so far away that their light takes several billion years to reach the earth. People on earth, therefore, see them as they were that long ago in the past. 4A/M2de

- Nine planets of very different size, composition, and surface features move around the sun in nearly circular orbits. Some planets have a variety of moons and even flat rings of rock and ice particles orbiting around them. Some of these planets and moons show evidence of geologic activity. The earth is orbited by one moon, many artificial satellites, and debris. 4A/M3

By the end of the 12th grade, students should know that

- The stars differ from each other in size, temperature, and age, but they appear to be made up of the same elements found on earth and behave according to the same physical principles. 4A/H1a
- Unlike the sun, most stars are in systems of two or more stars orbiting around one another. 4A/H1b
- On the basis of scientific evidence, the universe is estimated to be over ten billion years old. The current theory is that its entire contents expanded explosively from a hot, dense, chaotic mass. 4A/H2ab
- Stars condensed by gravity out of clouds of molecules of the lightest elements until nuclear fusion of the light elements into heavier ones began to occur. Fusion released great amounts of energy over millions of years. 4A/H2cd
- Eventually, some stars exploded, producing clouds containing heavy elements from which other stars and planets orbiting them could later condense. The process of star formation and destruction continues. 4A/H2ef
- Increasingly sophisticated technology is used to learn about the universe. Visual, radio, and X-ray telescopes collect information from across the entire spectrum of electromagnetic waves; computers handle data and complicated computations to interpret them; space probes send back data and materials from remote parts of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed. 4A/H3
- Mathematical models and computer simulations are used in studying evidence from many sources in order to form a scientific account of the universe. 4A/H4