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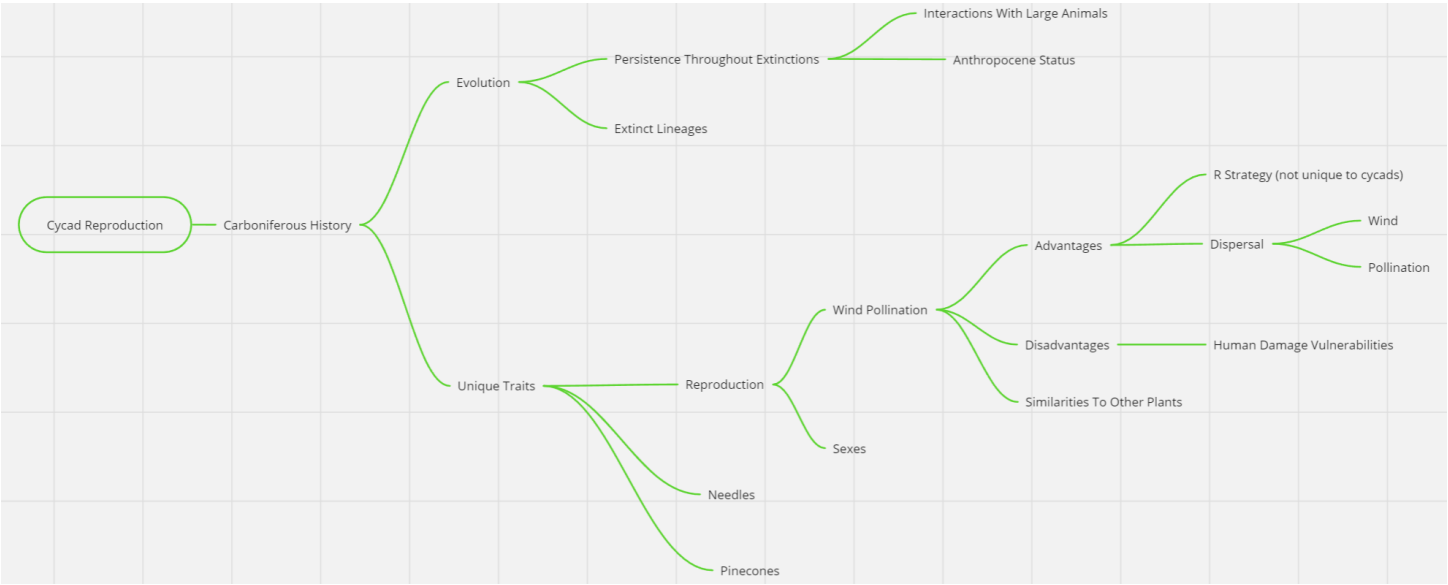
Final Project Summary & Annotated Bibliography

Key Scientific Concepts:

Cycad Reproduction



"Cycad Reproduction" Miroboard Mindmap

(1). Advantages of cone-based pollination.
Pollen is produced within the hardy scales of a male gymnosperm cone, which protects the pollen from harsh elements, then disperses them once weather conditions become preferable. Additionally, gymnosperm pollen can perform fertilization in much drier habitats than spores can, due to being able deposit sperm by utilizing their own cytoplasm rather than relying on external sources of water.

(2). Disadvantages of cone-based pollination.
Gymnosperms primarily rely on wind to disperse pollen. Yet rarely do windbound pollen successfully arrive upon a female cone, and are instead more likely to trap themselves in dirt, debris, water, or other environmental snags. As a result, gymnosperms must expend lots of energy producing copious volumes of pollen to increase the chance of them finding a mate.

(3). Phylogenetic relationships, similarities, and differences.
Unlike most other gymnosperms, cycads possess motile sperm, though it is unnecessary for them as the cytoplasm of the pollen cell itself pushes sperm towards the egg. This motile sperm is most likely a vestigial remnant retained from their damply-reliant ancestors.

Final Project Summary

Although I have many interests in animal reproduction, I am rather unfamiliar with plant reproduction, and so have desired to learn more about the sexual habits of cycads: an ancient order of plants that had flourished during the Permian Era (Wachtler, 2016)[1], and yet still persist today. They belong to a larger clade of plants called gymnosperms.

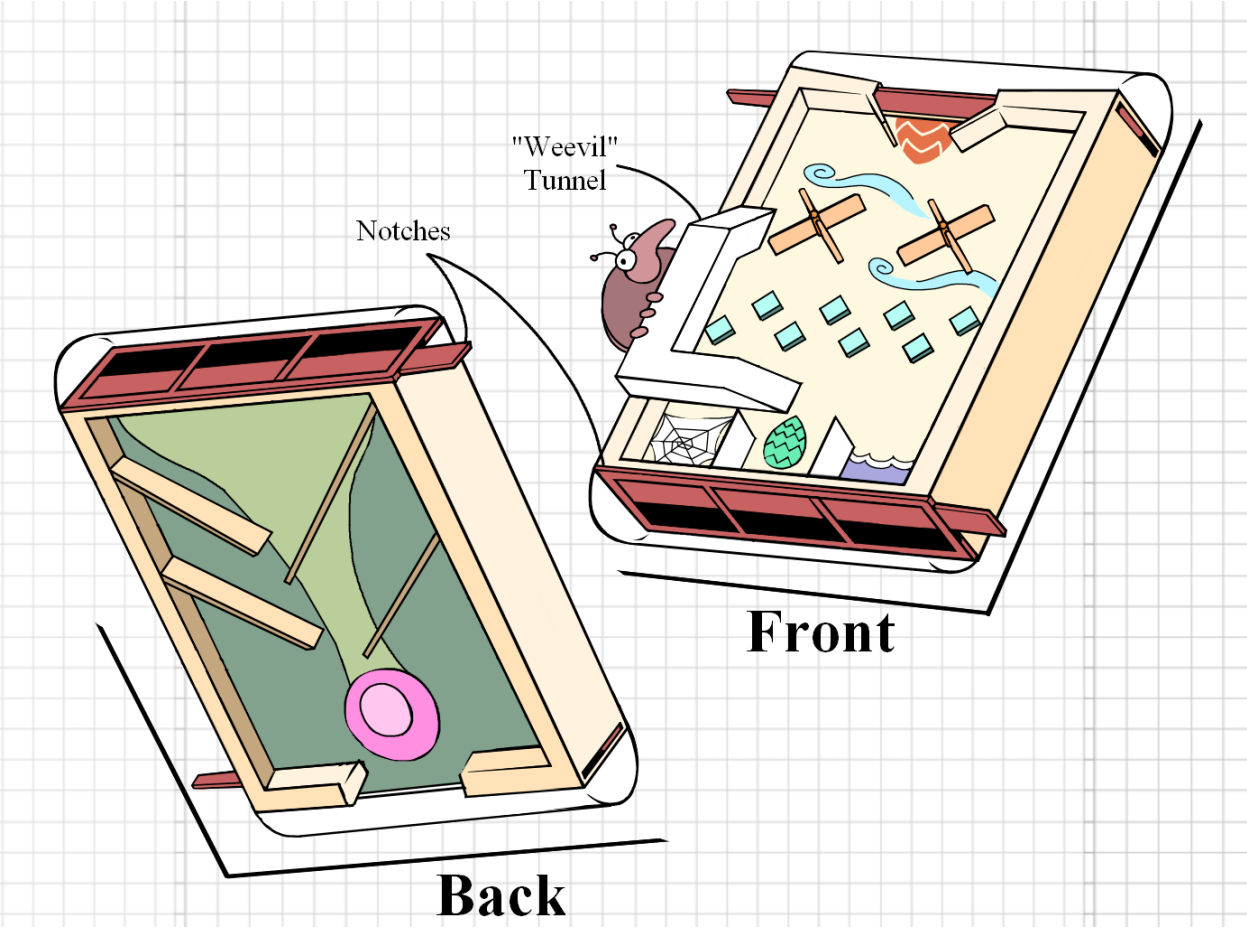
Gymnosperms are notable for being the first seed plants to evolve pollen grains (Breygina *et al.,* 2021)[2], which is considered a major milestone in terrestrial plant evolution. Whereas plant spores require a damp habitat for their sperm to travel via external liquid to nearby eggs (Atallah & Banks, 2015)[3], pollen grain cells expel their own cytoplasm as means to propel sperm into the egg, eliminating the need for moisture, and allowing gymnosperms to inhabit a variety of dry environments.

Gymnosperm pollen is produced and received by an organ called a cone (or strobilus), which acts as a protective camber, sheltering valuable pollen from harsh elements, such as fire (Burrows & Vargas, 2021)[4]. These precise reactions to the environment gives Gymnosperms an edge at inhabiting harsh environments, as they can prepare for future weather.

However, the chances of a pollen grain arriving upon a female cone is extremely low, thus the male cone must expend a great amount of energy to produce many cones, or one very large cone for increased pollen grain production, solely to heighten the chance that the pollen may arrive at a mate (Lu *et al.,* 2011).[5] Some cycads form symbiotic relationships with weevils, enticing them with heat and odor, whilst the weevils act as pollinators (Salzman *et al.,* 2021).[6]

Motile sperm is not required for pollen-bearing plants, as the pollen cell's cytoplasm manually pushes the sperm into the egg. As such, the sperm cells of angiosperms and many gymnosperms have lost the need for flagella - yet the sperm cells of cycads retain theirs. This unique sperm morphology renders cycads unique among gymnosperms, and thus they are considered the most basal members of their clade, as the presence of motile sperm is believed to be a vestigial leftover from their moisture-reliant ancestors[2].

For my final project, I desired to highlight the cycad's unusual sperm morphology, alongside the general advantages and disadvantages of cone-based reproduction. My initial attempt involved creating a toy.



The toy is a miniature plinko game containing marbles, representing pollen. A lid of transparent plastic seals the marbles inside. The marbles arrive at the top section (which is shaped as a male cone) and bounce their way down into funnels at the bottom, passing through pinwheel spinners along the way which represent wind (purely aesthetic). One of the funnels is plastered with an image of a female *cycas* cycad, representing the “winning” path. The other funnels lead to unsuccessful locations, such as being caught in debris or drifting out at sea. This represents the randomness of a gymnosperm pollen grain’s success of locating a female cone.

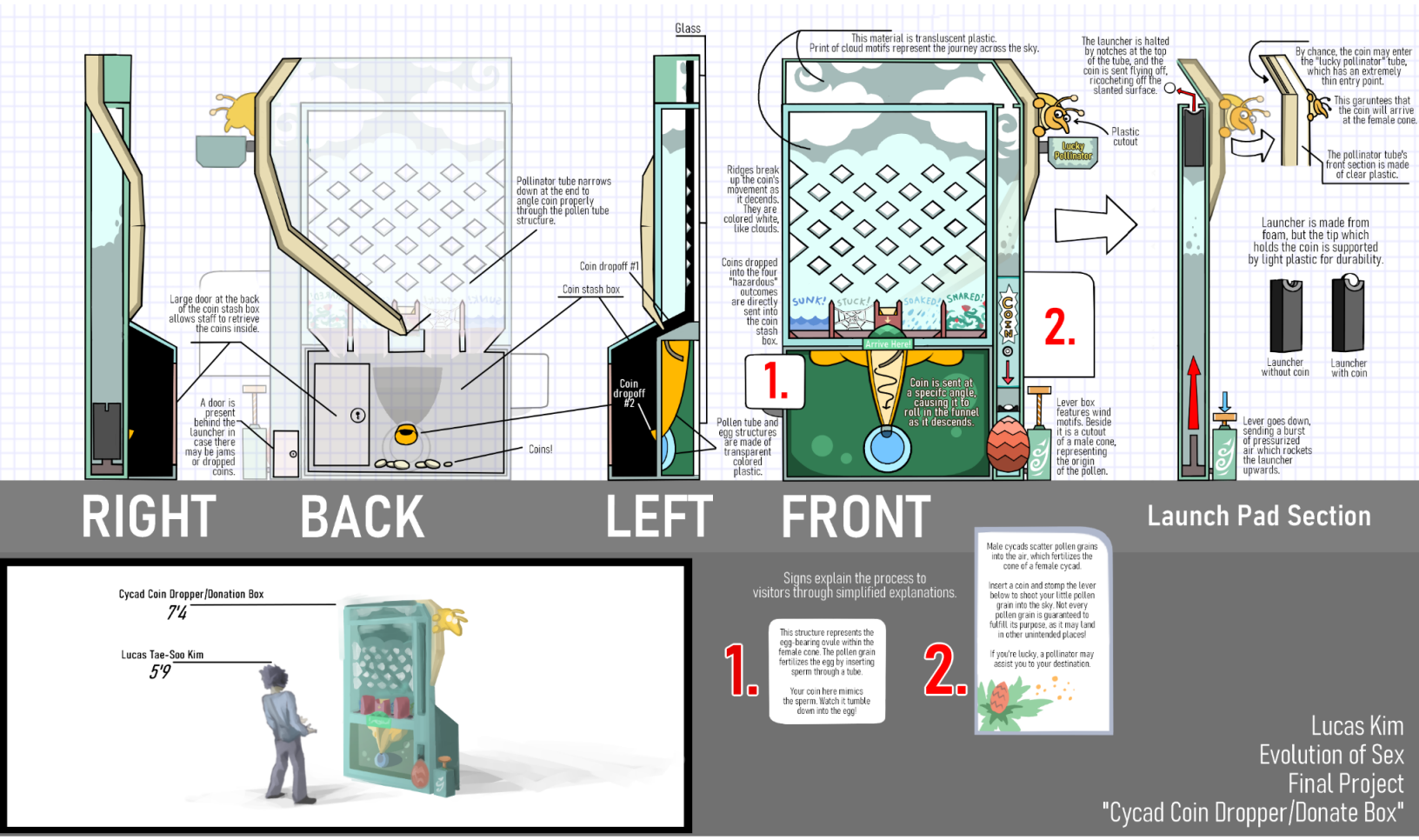
There is one special tube within the plinko notches that is guaranteed to lead marbles into the female cone. This is the “weevil” tunnel, which represents the great assistance which pollinators provide to deliver pollen.

A pulley positioned on each tip of the toy controls latches on the funnels. Pulling them will open grooves which transport the fallen marbles into the back layer of the toy, which resembles a pollen grain’s nuclei tube penetrating the archegonium/female sexual organ. A zigzagging path descends down into the egg positioned at the bottom, causing marbles to clack and tumble as they roll downwards, loosely representing the swimming movement of cycad’s uniquely motile sperm.

The material of the toy is made of thick plywood for the base, and hardy transparent plastic for the container exterior (so users can peek inside). Printed paper is glued onto the plywood.

The target audience for the toy are young children who may be enticed by the sounds and movements of the falling marbles, although curious adults interested in plant biology may appreciate the design too.

However, I transitioned away from the idea and remade the concept. Rather than attempt to create a toy, I instead envision a concept art for a cycad-themed “donate box” which can reside in museums and other educational centers. Users may donate a coin into the box and watch it bounce through the many obstacles below. In this scenario, the target audience is significantly broader, designed to target any generously donating visitor eager to see how the coin fumbles.



It is still technically a plinko game. The coin represents a single pollen grain, and wind now has an actual influence on it, as the user is required to generate a blast of gust with a lever to propel their coin upwards. A cutout of a male cone sits beside the launcher, mimicking how a real

pollen grain would detach off its parent cone via wind. As such, the pinwheels have been removed, as a metaphorical reference to wind is no longer needed when a literal process of it occurs.

Arriving at the female cone is now much harder due to its smaller entrypoint, making the chances more faithful to the real process. The “weevil” tunnel (named here as the Lucky Pollinator tunnel) is also now less likely to be achieved.

The pollen grain tube sculpture which leads into the female egg no longer causes the “pollen” to zigzag, and is instead flung at a sharp angle which causes the coin to spiral across the funnel walls as it descends: a process still not quite true to the actual movement of cycad sperm, but is nonetheless entertaining to watch, and still conveys motion in some form.

Practical immersion was not ignored, and much detail had also been spent into thinking about how the launching mechanism would function, how the paths would be organized, how the coins would move, and where the coins would be retrieved. In terms of overall concept, I find this to be much better grounded than my initial vision of a toy.

Annotated Bibliography

An analysis of prehistoric cycads and their diversity, while also attempting to form an up-to-date-model of the cycad lineage. Contains information about Early Permian cycads.

Michael, Wachtler. (2016). Cycad-evolving stages in the past. https://www.researchgate.net/publication/311608055_Cycad-evolving_stages_in_the_past

An overview of the evolution of gymnosperm’s unique pollen grains and the “primitive” anatomical features they possess to achieve pollination, alongside the diversification of pollen grain physiology among various different gymnosperms.

Breygina, Maria et al. “Pollen Germination and Pollen Tube Growth in Gymnosperms.” *Plants (Basel, Switzerland)* vol. 10,7 1301. 26 Jun. 2021, doi:10.3390/plants10071301, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8309077/

An introduction to the life cycle of ferns, sexual and asexual, and revealing their similarities and differences with angiosperms via biochemical studies. The motile sperm of ferns are mentioned here.

Atallah, Nadia M., and Jo Ann Banks. “Reproduction and the Pheromonal Regulation of Sex Type in Fern Gametophytes.” *Frontiers*, Frontiers, 7 Feb. 2015, www.frontiersin.org/articles/10.3389/fpls.2015.00100/full.

An investigation of some gymnosperm’s ability to resprout (repopulate after the presence of fire). There is also some explanation of cone morphology and durability.

Burrows, Geoffrey E. “Gymnosperm Resprouting-A Review.” *Plants (Basel, Switzerland)* vol. 10,12 2551. 23 Nov. 2021, doi:10.3390/plants10122551 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8705048/

A broad explanation of the various adaptations gymnosperms possess for efficient wind pollination dispersal, and the variety of ways of which different species use to disperse.

LuY., JinB., WangL., WangY., WangD., JiangX.-X., and ChenP.. 2011. Adaptation of male reproductive structures to wind pollination in gymnosperms: Cones and pollen grains. *Canadian Journal of Plant Science*. 91(5): 897-906. https://doi.org/10.4141/cjps2011-020

The various weevil species which specialize in pollinating cycads, and the history behind their coevolution.

Salzman, Shayla, et al. “Cycad-weevil pollination symbiosis is characterized by rapidly evolving and highly specific plant-insect chemical communication.” Frontiers in Plant Science, vol. 12, 2021, https://doi.org/10.3389/fpls.2021.639368.