The Continuous Environmental Tracking hypothesis—application in seed dormancy and germination in forest ecosystems

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God created creatures to multiply and fill the earth and imbued them with design features that enable them to diversify, persist, and occupy new habitats. Focused research using engineering principles with emphasis on biological design of organisms and their responses to natural conditions can be a productive way to better understand how God designed them to do this. The Continuous Environmental Tracking (CET) hypothesis incorporates human engineering analogues and assumes that organisms have been designed with intelligently engineered systems that include sensors, logic mechanisms, and output responses. Data suggest that forest seeds are constantly monitoring and responding to changing environmental conditions. Identified seed sensors can detect conditions such as light, smoke, and temperature. These sensors are connected to biochemical pathways that are logic mechanisms affecting output responses that inform the seed to remain dormant or germinate. These observations, similar to human engineered tracking systems, are consistent with CET predictions. The CET hypothesis provides a research protocol for building a creation model of biology. It guides researchers to focus on how organisms detect environmental conditions, trace biochemical and genetic pathways, and discover how these logic mechanisms help the organism address its ever-changing environment, in order to adapt, diversify, multiply, restore beauty, and persist.

For over 100 years, philosophical and material naturalists have hypothesized that current organism diversity and adaptation can be explained without invoking the supernatural. A key assumption of this traditional modernist interpretation is that organism adaptation and diversification are driven by arbitrary natural processes that are random, unguided, and unregulated.[1] If genetic changes provide a natural advantage to the organism, get passed on to future generations, and begin to change the genetic dynamics of populations (e.g. natural selection, gene flow, drift), then adaptation and diversification are taking place.[2] However, what many evolutionary biologists are recognizing is that these mechanisms are too simplistic and cannot explain biological observations for a host of adaptive mechanisms that include ecological, behavioural, genetic, and epigenetic responses.

The complexities surrounding organism relationships with one another and their environment continue to reveal labyrinthine processes we are just beginning to appreciate. For example, Duncan *et al.*[3] discuss the importance of epigenetic research which continues to show how organisms self-modify their chromatin and expressions of their DNA—without changes to nucleotide sequences—in response to detecting specific environmental conditions. More organisms continue to be identified as phenotypically plastic where one genome is capable of producing different phenotypes as specified responses targeted to the environmental circumstances it detects. Polyphenisms are a type of phenotypic plasticity where a single population may have multiple phenotypes in response to environmental cues such as temperature, nutrients, population densities, predators, and insolation.[4] For example, in response to nutrient availability and other environmental conditions, plants such as geraniums (*Geranium transversal*e) and jack-in-the-pulpits (*Arisaema triphyllum*) may change gender in a process known as gender diphasy.[5–7]

Gilbert discusses the importance of environmental conditions in biology where developmental programming is context-dependent such as reptiles, like snapping turtles (*Chelydra serpentina*), that exhibit temperature-dependent sex determination.[4] The traditional naturalistic interpretation is that gender is determined by soil temperature during the second trimester. But what if these observations could be reinterpreted as snapping turtles having an identifiable temperature sensor and the path of the developmental program is *internally selected* as a specific and necessary consequence of innate ‘if-then’ logical programming based on data about the temperature the embryo detects? In other words, is nature selecting or is the organism responding to natural conditions based on highly complex internal programming?

In order for organisms to relationally respond to one another and respond to their environment, they must have ways of detecting, identifying, and communicating with each other and the changing environmental conditions around them. They must be able to transmit that information through messaging pathways that inform specific locations of the genetic control centre, which in turn change behavioural or phenotypic responses, appropriate to the conditions and organisms they encounter. Because the traditional view does not adequately explain this biological complexity, there is discontent in the scientific ranks because they recognize a need to update naturalistic hypothetical mechanisms that can better explain these phenomena.[2,8,9]

Organism dynamics that are making it more difficult for traditional evolutionary mechanisms to explain include:

- Adaptations overwhelmingly appear targeted
- Organisms have programmed modification capability to produce new and functional phenotypes
- Organisms can track changing environmental conditions and adjust
- Diverse organisms repeatedly express similar morphological traits in similar environments
- Mechanisms appear highly regulated
- Adaptive genetic modifications appear internally controlled and non-random
- The genome is being viewed by many as a read and write library capable of revision
- Adaptation rates, and hence speciation, may be variable and can be rapid
- Some adaptations can be repeatable and predictable
- Some adaptations are reversible
- Adaptive mechanisms include genetic, epigenetic, developmental, founder effect, and ecological
- Observed transgenerational inheritance mechanisms include epigenetic, physiological, behavioural, and ecological [10]

These observations were summarized in a 2016 Royal Society meeting in London in November 2016, [11] and Guliuzza and Gaskill reinterpreted mechanisms for the above phenomena by proposing that biological functions are best explained by engineering principles as a step toward developing a theory of biological design.[10]

For biblical creation researchers, the Torah contains foundational information in the form of an outline of sequential and creative activities by the Author and Creator of these first week organisms and processes.[12] It is evident that God desires to be known and He has imparted His invisible qualities into the visible creation to remind us of our need to worship Him as Creator.[13] With those who have eyes to see, His attributes of beauty, relationship, and engineering prowess continue to inspire Christian researchers to learn about His world with the goal of building scientific models that give Christ glory and honour. With every discovery, we gain more insight into Him, His infinite wisdom, and His love. Consider, for example, complex biogeochemical cycles that are required for life. They powerfully illustrate God's love and provision, but also suggest incredibly elaborate and irreducibly complex systems design and relationships.[14,15] Conversely, it is also evident that there is something wrong with creation, as pain, suffering, and death are a characteristic of our world. These 'birth pains' are consistent with God's curse and judgment on the planet because of man's rebellion.[16–18]

It is within this creation framework that we reject purely naturalistic explanations both for the origin of life and the ability of organisms to adapt and diversify. We understand that the interpretations of adaptational processes have naturalistic bias attached to them, so we use this term with the idea that organisms are responding to natural conditions because they have been engineered to do so. If an organism goes extinct, it is either because they were not designed for particular environmental conditions or there were extreme events that caused their demise (e.g. The Flood, anthropogenic factors such as extermination or habitat loss).

The Continuous Environmental Tracking (CET) hypothesis was proposed as an engineering and relational approach, based on God's attributes that could contribute key scaffolding for a creation model of biological and ecological processes that include: adaptation, symbioses, biogeochemical cycles, extirpation, extinction, epigenetics, phenotypic plasticity, and rapid baraminological diversification.[11] We emphasize that organisms are not being viewed as machines but as living entities designed with varying abilities to enter into relationships with one another and respond to changing environments in order to fit-and-fill and/or replace and persist in ecological communities. That creatures can adapt to a kaleidoscope of seemingly insurmountable environmental challenges provides an ongoing display of the phenomenal engineering that went into their design.

Based on our current understanding of organism relationships and functions, the CET hypothesis proposes that natural processes are not key drivers of organism change but rather organisms have been designed to actively monitor changing natural conditions and respond to them by self-adjusting, using programmed engineering tools, similar to how human engineers might design robotic or drone systems. Therefore, we hypothesize that all organisms have been designed with the following functions observed in human tracking systems:

1. *Sensors* which are designed to monitor specific environmental conditions, while minimally affecting the environmental variable being studied. Sensors must be ready to collect data by active surveillance and must be connected to the total organism system.
2. *Logic mechanisms* include 'if-then' types of on-off switches and gates connected to the sensors and genetic mechanisms that control organism responses.
3. *Output responses* where God has programmed organisms to change and respond appropriately to the new

environmental condition in order to continually fill new environmental niches and persist in them.

Expected predictions and the CET hypothesis: criteria for acceptance/rejection

This hypothesis is based on systems designed by human engineers. When studying well-designed machines like robotic drones, they have detectors, logic-centred algorithms, and the ability to locate, track, and follow a target. As far as we know, all organisms are able to monitor, track, and respond to their environment. Consider the bacterial and fungal networks that coordinate plant and animal communication and survival,[19] plants mounting chemical defences as they respond to leaf vibrations caused by herbivorous insects,[20] mycorrhizal fungi competing with soil bacteria to affect soil carbon storage,[21] underground fungal networks warning plants of aphid attacks,[22] increasing CO$_2$ concentrations and the associated intrinsic water use efficiency in some plants,[23] above-ground environmental stress detected as a stimulus for below-ground communication and response to that stress,[24] and orchid seed germination, survival, and persistence requiring obligate symbioses with fungi.[25] These phenotypic and genetic changes are often rapid, predictable, heritable, and can stabilize in populations, but not necessarily in particular individuals. When studying these phenomena, we can predict where to search for possible sensors and narrow down their locations. Once found we can trace biochemical pathways and networks as the probable logic mechanisms that will somehow affect the genetics/epigenetics and or biochemistry that modulates the organism so that it can respond accordingly. If no such mechanisms are located, then the CET hypothesis can be falsified. Based on the above criteria, we will both apply and test the CET hypothesis for seed dormancy and germination specifically, how a seed 'knows' when to germinate especially when lying dormant in forest soil for 60 years or more.[26]

An overview of forest ecosystems

It is estimated that forests make up 30% of the earth's terrestrial biomes which consist of 3.9 billion ha (9.6 billion acres) and about 3 trillion trees, depending on measurement parameters of vegetation.[27,28] Some evidence suggests that vegetation is increasing as the planet continues to 'green'.[29] Forest ecosystems consist of complex organism and environmental relationships comprised of currently incomprehensible systems where communication and interactions between organisms and with the abiotic environment are prevalent from the forest soil to the forest canopy. These relationships and processes combine to produce forest ecosystems capable of crucial ecological and biospheric services that include: oxygen production, organism habitat, soil productivity, erosion control, flood regulation, shade and microclimate control, water purification, stream ecosystem health, global climate regulation, community succession, and aesthetics appreciation and recreation for humans.[30]

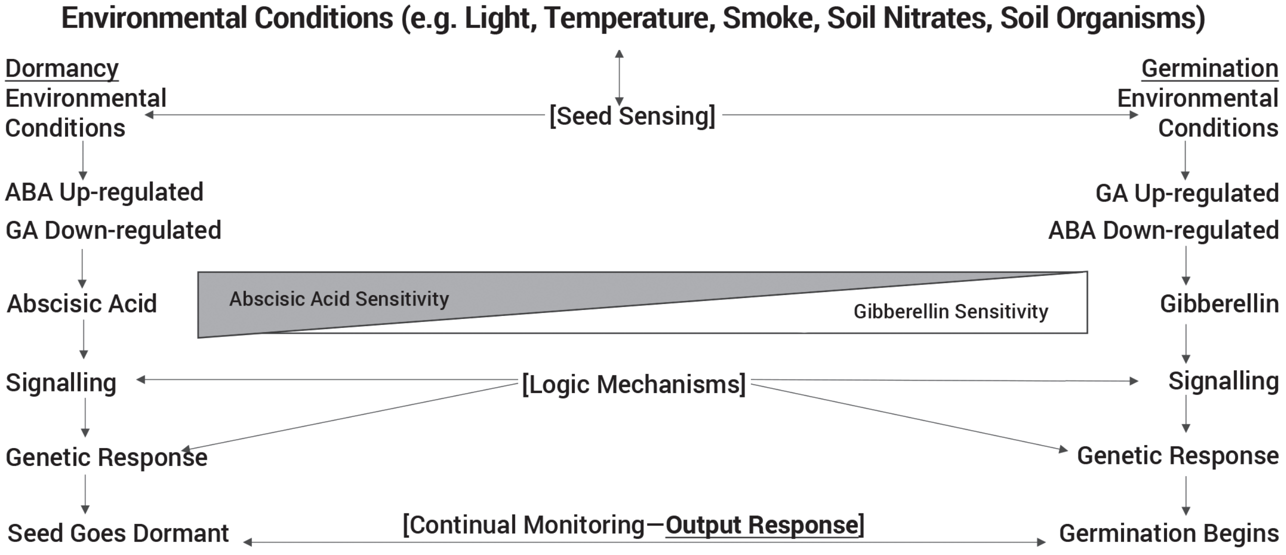

Figure 1. Continuous Environmental Tracking (CET) application to ABA:GA model of dormancy regulation (after Taiz *et al.*,[34] p. 518). The Hormone Balance theory simplistically models the concentrations of two antagonistic phytohormones: abscisic acid (ABA) and gibberellin (GA). ABA up-regulation and GA down-regulation promote seed dormancy and when environmental conditions are right, GA up-regulation and ABA down-regulation promote germination.[34,41] Research suggests that there is much more going on than just the concentrations of ABA:GA. However, complexity with seed dormancy/germination phenomena is consistent with the CET hypothesis since seeds continually monitor their environment, and require sophisticated engineering mechanisms that include sensors, logic mechanisms, and output responses.

Forest systems are constantly challenged by natural disturbance. Perturbations include; forest fire, flood, earthquake, volcanic eruption, heavy snow, intense freeze/thaw, and various pathogens. God has designed these systems to express a cycle (or phases) of adaptive responses, but how they recover is dependent on organism composition, structural and/or spatial patterns of system elements, and systems level characteristics that include biogeochemical cycling, microclimate, species diversity, topography, genetics/epigenetics, and forest productivity.[31] For example, fire-adaptable trees like Table Mountain pine (*Pinus pungens*) and lodgepole pine (*Pinus contorta*) have heat-sensing (serotinous) cones that hold viable seeds. When a fire disrupts these forests, heat from the fire is detected by the cones, causing them to open and disperse the new seeds that will germinate, replace, and establish the previous forest. One of the system components that determine how forest environments bounce back from challenges are the legacies left behind.[32] Legacies are the survivors of extreme disturbance and include: serotinous cone-bearing trees and the ability of seeds to lie dormant and viable, sometimes for thousands of years and germinating when conditions permit.[33,34]

The complexity of seed dormancy

When seeds drop from the mother plant on to the forest soil, they accumulate and form a soil seed bank. This phenomenon could be interpreted as God's design for forests to make long-term deposits for future forest emergencies.[35] Seeds must be able to monitor environmental conditions and be programmed in a way to germinate when conditions are conducive for healthy seed establishment. The steps toward germination include: Phase 1, water imbibition via seed coat under proper conditions (e.g. humidity, light, soil temperature, nitrate concentrations, smoke, oxygen); Phase 2, end of water uptake; and Phase 3 embryonic root growth (protuberance).[36] However, as simple as the above may sound, all details of seed endurance, dormancy, and germination continue to evade researchers. There are times of the year when some environmental variables are conducive to germination, but the seed does not germinate. In this instance the seed is said to be dormant. Dormancy is important because it provides the needed time for seeds to disperse to appropriate microclimates, gives them a better germination rate in the appropriate growing season or spatial conditions, and prevents germination during deleterious environmental conditions.[37] General seed states are differentiated into primary dormancy, secondary dormancy, and vivipary. Vivipary describes seeds that are germinating on the mother plant before dispersal. Primary dormancy refers to seeds that remain dormant under normal environmental conditions while secondary dormancy refers to non-dormant seeds that do not germinate when they detect unfavourable environmental conditions.[34] As research progresses in this area, it is clear that seed condition categories do not properly describe the complexity surrounding dormancy and germination.

Baskin and Baskin[38] recognize that seed dormancy mechanisms are many and varied depending on plant species, and whose responses are tailored to environmental conditions and other organisms present. Consequently, they have proposed a dormancy classification system. *Physiological dormancy,* further subdivided into non-deep, intermediate, and deep, is controlled by physiological processes within the seed. *Morphological dormancy* occurs when the embryo is too small, therefore the seed will not germinate until the embryo reaches full size. *Morphophysiological dormancy* is seeds having both an underdeveloped embryo and a physiological variable controlling germination. *Physical dormancy* is controlled by *traits of the seed coat* such as its water impermeability and reaction to natural processes such as heat, chemical scarification, or physical scarification that physically break down the seed coat and promote germination. In *Combinational dormancy* the embryo is dormant because the seed coat is both water impermeable and has a physiological mechanism controlling germination.

Dormancy mechanisms

A great deal of research is being done on seed dormancy and germination mechanisms using the model plant known as thale cress (*Arabidopsis thaliana*).[39,40] Though many questions remain about dormancy mechanisms, much has been learned. According to the Hormone Balance Theory (figure 1), the concentrations of two antagonistic phytohormones have significant, but not the only roles involved in germination and dormancy. These plant hormones are abscisic acid (ABA) and gibberellin (GA). They are antagonistic because they negatively influence each other and their signalling pathways.[39] ABA biosynthesis (up-regulation) and GA catabolism (down-regulation) promote seed dormancy and when the time and conditions are right, GA up-regulation and ABA down-regulation promote germination.[35,41] Two factors are important in determining whether the seed remains dormant or begins to germinate: the concentration of the phytohormones and the ability of seed tissues to detect them. Other hormones are also involved and it has been shown that ethylene and brassinosteroids can inhibit ABA and promote germination or ABA can inhibit ethylene biosynthesis favouring dormancy or auxins can promote dormancy in conjunction with ABA, while brassinosteroids can increase the rate of ethylene biosynthesis, favouring germination.[34,41] The biochemical cascades and signalling pathways are highly complex but the complexity is magnified because the above processes and responses the plant makes depend on environmental conditions, seed morphology, and seed physiology.[42]

CET hypothesis applied and tested for forest seed dormancy and germination: the sensors

Regardless of the above mechanisms, seeds must monitor environmental conditions to 'know' when to remain dormant and when to germinate. Experimental research suggests that seeds in the soil are constantly adjusting phytohormone ratios, which inform dormancy/germination responses based on changing environmental conditions.[34,39] There is also evidence that some plants monitor changing environmental conditions (e.g. low temperatures) before flowering, fruit, and seed production and later enhance the dormancy of seeds. In other words, the mother plant can pass down information about the environmental conditions it is experiencing and prepare the seeds for those conditions before the seeds are produced. These data, and other lines of evidence, indicate that at least some plants are capable of memory storage, used in a mother-to-offspring anticipatory system whose inherited information in the next generation prepares them to be optimally suited for the conditions the designed program anticipates they will encounter.[40,43,44] Just how plants are monitoring the environment is a question being actively researched. Presently there are at least three seed sensors that have been identified in detecting light, temperature, and smoke.

Phytochromes: primary sensor for light

Plants require varying light characteristics for germination and these are often species-dependent. For example, birch trees (*Betula sp.*) require long days while Eastern hemlocks (*Tsuga canadensis*) require short days.[45] Phytochromes (among others) have been well described as the primary photoreceptors (sensors) capable of absorbing photons of a given wavelength, producing energy used to signal a cascade of reactions that trigger genes, which causes a plant to respond (see figure 1). Phytochromes primarily absorb the red to far red (600–750 nm) most efficiently, but can also absorb blue (350–500 nm), and UV-A (320–400 nm).[45] Phytochrome structures vary depending on their function but all consist of a protein attached to a chromophore (non-protein molecule).[45] Depending on the protein structure and function, phytochromes are sensitive to various properties of light. Some are sensitive to the quantity of light, others are sensitive to the quality of light (e.g. wavelength dependency and associated action spectra), and others are designed for light intensity parameters, while others operate based on light duration.[45] We also know that multiple photoreceptors can be found on one plant and they interact with each other in complex ways. These programmed abilities in forest seeds ensure that at least some seeds will germinate and establish to fill new niches, persist over time, and/or replace a forest that has been destroyed.

Delay of germination-1 gene: temperature sensor

Genes have been identified in some plants that are key regulators of dormancy and germination.[39] These genes are identified as *Delay of Germination 1* (*DOG 1*) and *Reduced Dormancy 5* (*RDO5*). More will be discussed about these logic mechanisms below, but data suggest that *DOG-1* may also have a role as an important seed temperature sensor.[39] Some seeds require a period of time at low temperatures (e.g. 0°–10°C), especially important in temperate climes for seed dispersal in autumn where seeds must wait for the best conditions available in spring and summer.[39]

KARRIKIN-INSENSITIVE-2: smoke sensor

Karrikins are compounds that are classified as butanolides. They are found in the smoke and ash produced by wild fires caused by the burning of cellulose and other sugars that make up vegetation. Precipitation leaches the karrikins from the ash into the seed bank and they have been shown to promote germination in many plant families.[46] One protein known as KARRIKIN-INSENSITIVE-2 (KAI2) has been identified as a smoke sensor, detecting karrikins and starting a germination signalling process that is still being elucidated.[47,48] Sensors found in seeds that detect light, temperature, and smoke are likely just the beginning when it comes to new sensors

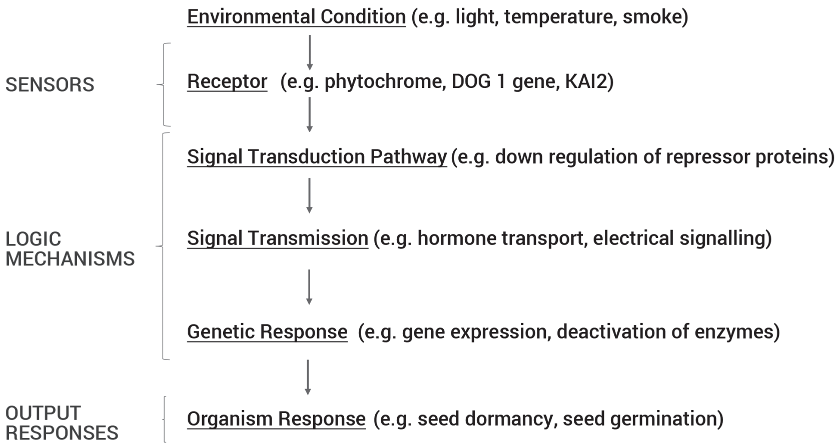

Figure 2. A simplistic model of signal transduction theory in plants, and the model's consistency with the Continuous Environmental Tracking (CET) hypothesis (after Taiz *et al.*,[34] p. 409). Dormancy/germination is being regulated by several independent biochemical pathways that require sensors that communicate environmental conditions through signal transductions and transmissions that modify a number of genetic and epigenetic responses, which then inform the organism as to its output response.[39]

detecting various environmental conditions being discovered and identified.

CET: logic mechanisms and output responses

As for responses seeds must make, all sensors connected to logic mechanisms ultimately determine phytohormone up-regulation and down-regulation, along with other variables, which ultimately trigger output responses of dormancy or germination. Many logic mechanisms have been worked out, but much research is required in order to fully identify cascades and genetic responses and interactions that lead to variable seed responses.

In biology, general models for signal transduction have been developed and are consistent with the CET hypothesis. Figure 2 shows one simplistic version. Nee *et al.*[39] summarize some of what is known about dormancy regulators which are types of logic mechanisms. Hormones like ABA, GA, and ethylene, discussed above, are well-known regulators. However, at least three genes have been identified as regulators and they are *DOG-1*, *RDO5*, and *MOTHER of FT* (*MFT*). *DOG-1* not only seems to be involved with sensing soil temperature conditions, but also encodes a protein with an unknown function that is correlated with keeping the seed dormant. Similarly, *RDO5* codes for protein phosphatase 2C. Technically this protein is a pseudophosphatase which is a subcategory of the phosphatase family. They are thought to be chemically inactive but may help in biochemical signalling. High protein concentrations from these active genes suggest they are correlated with the output response of seed dormancy, independent of ABA synthesis, though both are required. *MFT* encodes a binding protein called phosphatidyl ethanolamine and acts as a negative feedback with ABA up-regulation, promoting the output response of germination.

Data suggest that epigenetic regulators, in the form of chromatin restructuring, correspond with transcriptional differences involved with seed transitioning through development, dormancy, and germination.[39] Chromatin modifiers have been discovered and, depending on how chromatin is changed, will affect transcriptional processes such as acetylation (adding an acetyl group to a compound) and potentially affecting gene expression and metabolism, ubiquitination (adding a small regulatory protein to another protein) which can mark them for destruction, prevent other interactions with proteins, and affect their functioning. Finally, chromatin changes can determine methylation (addition of a methyl group to a substrate) which can alter gene expression, processing of RNAs, and protein function. All of these processes are logic mechanisms that directly control seed output responses toward dormancy or germination (see figure 2).

Some metabolic processes are temperature sensitive and there is evidence that this sensitivity is exploited as part of an innate logic system as a switching element. For example, Xia *et al*[36] found evidence that in seeds, at certain environmental temperatures, glycolysis and citric acid cycle metabolism decrease with an increase in sucrose metabolism which has been shown to break dormancy. The authors suggest that the regulation of the enzymes involved with the above metabolic processes is occurring at the post-translational level, affecting the output response to germinate.

Conclusions

Over the years, researchers have been formulating models that included identification of seed sensors, logic functions, and programmed responses that fit CET hypothesis predictions (figure 2). They are even using the term sensor, but not equating the term and processes with human-engineered analogues. Legacies left behind after forest disturbance, such as seeds accumulating in forest seed banks, must be able to monitor their environment and respond accordingly. We explain these ecological relationships within a creationist theory of biological design which includes a design-based, organism-focused model of adaptation; CET. We desired to test the CET hypothesis by examining if it could explain seed dormancy and germination. The test questions were: 1) do seeds have the key tracking system elements of sensors, logic mechanisms, and output responses; and 2) do seeds seem to be using these elements to track environmental changes as part of a dispersal-dormancy-germination plan? Our findings indicate seeds are using tracking system elements that correspond to human-designed tracking systems, and that seeds do seem to use these elements in order to continuously track and process data about their external (and internal) conditions producing responses which seem to optimize their potential germination success. These findings are consistent with the CET model expectations.

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