Olin College of Engineering, MA, USA

Thesis

Holistic engineering and a renewed science of holism for a thriving world

What does it mean to be alive and create as a 21st-century technologist?

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Abstract

We see a misalignment between the engineering field's constitutive-interests rooted in the reductionist sciences and the needs of the 21st century in the socio-political, environmental, and spiritual realms. Following Habermas's critical theory, the knowledge-constitutive interest of the natural and reductionist sciences lie primarily in the manipulation of the physical world for the purpose of predictable and quantifiable outcomes by reducing the studied system to its smallest components. Such interests are unfit to understand and intervene in our world; a living world of dynamic complexity. We argue that a renewed science of holism will create the conditions for a critical engineering education that can mimic the properties of living systems to recreate a thriving existence for all living beings on this planet. In this thesis, we identify six loose web-nodes to draw a picture of a science for the whole: (1) Natural phenomena such as emergence, self-organization, or autopoiesis acquaint us with the nature of nature. (2) The study of our world brings us closer to our cosmos's mysteries, which naturally introduces spirituality to the holistic web. (3) Dynamically complex systems theory attempts to understand the relationships between parts of the system to make assumptions about future behavior or opportunities for intervention. (5) Practices that are commensurate with the nature of reality are crucial for an effective engagement with living systems. Such practices include methods for a co-creation of the future and research and learning methodologies that embrace unpredictable emergence of insights and emancipate us from hidden oppressive power structures. (6) Lastly, a holistic science welcomes the reductionist sciences to analyze, predict, and control non-living, un-complex systems. Our hope is that a holistic science will re-shape engineers' understanding to learn and interact with our world to recreate the nature of nature in our systems: a thriving existence for all.

Keywords: holism, dynamic complexity, engineering education, co-creation, experiential learning, systems thinking

Preamble

In defense of this thesis
I write this thesis in a moment in time which has come about through a rich human history, which I am not going to unpack. My journey to explore holistic engineering has been enabled by the year-long off-grid micro-campus experience at Woodland Harvest Mountain Farm during the COVID-19 pandemic. Many beautiful conversations with my community members, friends, mentors, and advisors have further shaped my perception of the whole and its relationship to engineering.
Anything that anyone says about holism is necessarily incomplete including my own perspective. While big parts of this journey were related to understanding Western (academic) imperialism, my ability to look over the boarder was limited by my accessible languages, English and German. As you will notice, most papers cited are US-American or Eurocentric. I consider this thesis the beginning of my own process of understanding our whole reality and its relationship to engineering. It is not my intend to define what holism is or to create the illusion of a finished work. I hope to offer loose inspirational web-nodes of holism to allow the reader to go on their own journey of the discovery of the whole and its relationship to engineering.

My use of pronouns
All ideas in this paper have come into existence through conversations with my advisors, friends, and mentors. Their thoughts live on in my thoughts and it felt unnatural to ignore this connection by using the pronoun *I*. I therefore chose to use the pronoun *we*.

Updates on this thesis
While the original version of this document is my officially submitted thesis, I will keep working on it to draw a more cohesive and holistic picture. You can find the most recent version of this document by clicking on the link below:

`leonsanten.info/holistic_Engineering_most_recent.html`

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Introduction 1

Earth has entered a new geological epoch, the anthropocene, that is shaped by humanity's collective actions. Humanity's actions on this planet caused climate change, oppressive social systems, and economic disparity. Before humans interrupted the living systems on our planet, these ecosystems provided conditions for a thriving existence for all life. In the state of thriving, organisms grow and flourish beyond mere survival. It is clear that the present trajectory of anthropogenic climate change is threatening the well-being of many planetary species. This thesis is about a shift in engineering education aims at (re-)creating the conditions for all to thrive. For humans, thriving means to exist beyond mere survival and flourish by having equal access to the material and social/relational conditions to develop their talents or capacities to live up to their fullest potential.

Thinking about possible solutions, we have to remind ourselves that conditions for a thriving existence on planet earth existed before humans created civilizations or agriculture. We believe that engineers among many others can play a critical role in revitalizing our focus to create a world that allows a thriving existence for all, including all living beings and living systems such as plants, rainforests, and humans. Such an existence requires environmental sustainability as much it requires social justice. As nature thrives without us, we argue that we need to task ourselves to become nature's apprentice to mimic the principles that lead to a thriving existence. We believe we need to re-learn the art of biomimicry; learning to live sustainably from nature. Biomimicry on a systems level would inform our cycles of innovation and challenge us to create systems that are closed-loop and conducive to life. The essence of nature is the mystery of emergence. Things come into existence as a process of emergence from the whole reality. This reality is an ever-changing, complex field of forces and relationships. With an aim of systemic thriving, it is necessary to understand the relationship between our environmental conditions and the phenomenon of emergence to facilitate a healing process on earth.

In this thesis, we take the position that legacy science represents a powerful but limited view on the world. Disciplines have come into being through breaking down systems into their smallest components resulting in fields of knowledge that are artificially separated by profession or discipline. Due to the process of fragmenting the whole to a model of basic components, we have created a scientific blind spot for the whole. Our attention is similarly fragmented. In its industrial and militaristic incarnation in the 20th century, the engineering profession sprouted out of the seed of a science that abstracted from a whole reality. Our mental models are not neutral; they are thought structures that consciously and unconsciously shape our behavior. When we forget that we have learned them, we speak of unconscious models. Implicit biases are examples of unconscious mental models that are derivatives of our culture, shaping our behavior in unconscious ways The result of such an engineering field is a tall tree that bears the same fruits of fragmentation of the whole. The mental models of the reductionist sciences are incommensurate with the nature of reality, and therefore its fruits are not conducive to a thriving environment. On the contrary, a great deal of modern science and technology has harmed our eco-systems.

The nature of reality is that it is whole, all-encompassing, interconnected. I argue that a renewed science of holism will create the conditions for an engineering education that can mimic the properties of living systems to recreate a thriving existence for all living beings. Biomimicry and holistic science are mental models to learn from, emulate, and live with nature. They are deeply rooted in past cultures and wisdoms around nature. Therefore, biomimicry and holistic science are innovations as well as an act of remembering and an active engagement with the blind spot that our reductionist worldview created when we convinced ourselves that we no longer needed nature's help [1] . A holistic science pays attention to the interdependence and impermanence of all things. In other words, living systems require us to live in reciprocity and are dynamically complex. They always change and follow non-linear rules.

[1]: Benyus (2002), *Biomimicry: Innovation Inspired by Nature*

Prigogine and Nicolis observe that our world's complexity is deeply rooted in our physical world: "Complex behavior no longer appears to be a singularity in the otherwise uneventful history of a physical system. Rather, it is realised that it is deeply rooted into physics, that [complexity] may emerge and disappear repeatedly as the conditions vary, and even that it can coexist with the more familiar simple static behavior" [2] .

[2]: Prigogine et al., (1985). 'Self-organization in Nonequilibrium Systems: Towards a Dynamics of Complexity'.; p. 7

We therefore believe that an engineering education that is commensurate with reality needs to be holistic. Only engineering work that emerges from a holistic environment can re-create the properties necessary for a flourishing web of life. Among others, we see the following broad web-nodes as points of attraction in a holistic science and education:

Web-nodes of a holistic science

- Phenomena around life and their teachings about reality
- Dynamically complex systems theory to offer a language to describe natural characteristics
- Methodologies to learn about our world that are commensurate with the nature of reality to replace the current scientific method
- Spiritual engagement with ourselves and discovering our inner source coming from the mind, body, and spirit
- Methodologies for co-existence and especially co-creation to bring forth social innovation
- Reductionist sciences as part of the whole, fit for specific circumstances

Phenomena around life such as emergence and self-organization can teach us about the nature of reality. Due to the complex interplay between different parts of systems, we are in need of a framework or lens that attempts to embrace the whole. Systems theory, also a model with limitations, tries to integrate all disciplines into one big-trans discipline to develop tools for understanding living systems. We see its strength in unveiling the hidden flows of a system. However, no complexity theory can deliver a finalized explanation of the world [3] . As the legacy reductionist methods are limited in their approach to investigating our reality, new methodologies of scientific inquiry are necessary. Emancipatory action research, for instance, shifts our attention from a quantitative inquiry of a research object to a deeper, contextualized understanding of a research subject [4] . Inquiry of our world inevitably lead us to the mysteries of emergence and existence. Therefore, spirituality is crucial for any curious engagement with reality that is inevitably an inquiry of the mysteries of the universe and the mysteries inside ourselves. Spirituality on both the individual and collective level has the potential to shift our awareness. Personal practices of mindfulness increase awareness around our inner source, unconscious models, values, and needs. One can start to see the system inside one-self. Collective practices, on the other hand, allow the larger system to see itself, shift its collective awareness, and practice compassion. We see the cultivation of mindful practices as the path to shifting our awareness, sensing the present, and exploring future opportunities. Methodologies for successful co-existence and co-creation are therefore in the center of any (engineering) endeavor that seeks to create meaningful change. Lastly, we shall not forget about the extremely useful knowledge and methods derived from the reductionist sciences. There is a great set of engineering wisdom and tradition that is irreplaceable for analyzing, designing, predicting, and building simple systems. Oftentimes, simple systems display linear relationships between parts of the system. Knowledge and intuition around working with linear, simple systems is necessary for a safe and successful engineering process and should not be underestimated in its difficulty to teach and learn.

[3]: Gough (2012), 'Complexity, complexity reduction, and 'methodological borrowing' in educational inquiry';

[4]: Ledwith (2017), 'Emancipatory action research as a critical living praxis: from dominant narratives to counternarrative';

In the following paper, we draw out loose web-nodes for an engineering education for a thriving existence. We believe a thriving existence for everyone should be the goal of engineering work. We identify two base conditions for a thriving human experience. Humans need to have what is due them and experience systemic justice . In the words of Kate Raworth, our vision is to create a dynamic balance that creates "human prosperity in a flourishing web of life" [5] .

[5]: Raworth (2018), *Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist*;

Enriching the Engineering Frame of Understanding: Holism

2

With a progressive attitude and yearning for innovation, technical educational and research institutions across the Western hemisphere seek to address issues of the 21st century. In their mission statements, the Massachusetts Institute of Technology states to "work wisely, creatively, and effectively for the betterment of humankind" and the Technical University of Munich seeks to "develop talents in all their diversity to become responsible, broad-minded individuals and empower them to shape the progress of innovation for people, nature and society" [6, 7] .

[6]: MIT, *1.1 Mission and Objectives | Policies*, https://policies.mit.edu/policies-procedures/10-institute/11-mission-and-objectives;
[7]: TUM, *Mission Statement*, https://www.tum.de/en/about-tum/our-university/mission-statement/;

We do not seek to critique these aspirations, but instead want to shift our focus to the goals of conventional engineering curricula. These curricula mostly include knowledge in the field of the natural sciences and leave the cultural and critical sciences aside. Our critique on this educational structure follows Habermas' critical theory that every field of knowledge has its knowledge-constitutive interests that serve some deeply-rooted interests coming from the survival of the human species [8] .

[8]: Mingers (1992), 'Recent Developments in Critical Management Science';

We see a misalignment between the engineering field's focus that is organized around technical knowledge-constitutive interests and the needs of the 21st century in the social, environmental, and spiritual realms. This first part of the paper will explore the identity of engineering and interrogate why we need a shift from a reductionist worldview to a holistic worldview.

2.1 What is engineering?

The engineering profession has defined itself through its emergence in specific parts of our society. Most engineers work for corporate organizations or the military, and mostly solve industrial, commercial, or military problems [9] . Most commonly, engineering students break problems down into smaller parts, solve the smaller bits, and work back up to a final solution. Engineering education relies on a great field of engineering tradition to create a plan for the present and future. We see this knowledge and tradition organized around technical knowledge that services the validity check of the scientific method.

[9]: Riley (2005), *Engineering and Social Justice*;

In the natural sciences, valid knowledge has to abide by the standards of the scientific method. These are laws based on value-free, empirical analysis and testing that are upheld as a universal standard. However, we take the stance that the scientific method and therefore operational research are neither value-free nor objective. As Habermas mentions in his critical theory, every field of knowledge has its knowledge-constitutive interests that emerged from the initial intention behind the creation of the field of knowledge. In the case of the natural and reductionist sciences, we see the primary interest in the manipulation of the physical world for the purpose of predictable and quantifiable outcomes [10] .

[10]: Habermas (1972), *Knowledge & Human Interests*;

Engineering students, however, learn little about cultural and critical thinking. We see engineering education largely organized around capitalist ideology, which seeks to predict and control its outcomes. We see a strong connection between this particular use orientation of knowledge and the knowledge-constitutive interests of the natural sciences. Supporting Marx' theory, the superstructure of current educational models exists to develop the means of production [8] . For instance, we observe that learning outcomes in the engineering field are often measured by their direct translation into income or economic value. Learning insights that are more unique and less quantifiable are therefore less visible to the educational system.

[8]: Mingers (1992), 'Recent Developments in Critical Management Science';

Due to the knowledge-constitutive interests, knowledge about ourselves and our environment produced by the natural and social sciences is inevitably partial or systematically distorted. In order to reflect on the distortion of our knowledge, we need the critical sciences (philosophy or spirituality) to emancipate ourselves to reveal our illusions and distortions and make more truthful claims. Habermas' critical theory and a research methodology called "emancipatory action research" attempt to make more truthful claims by applying this critical lense [4, 8]. In the section on methodologies for learning, we will highlight some of their practices.

Modern science is subject to social flows in our society. Colonialist behavior came into existence when the seeds of the scientific method started to sprout . Modern science and subsequent economic activity was built on a colonialist, violent world structure [11] . Therefore, we can find authoritarian, oppressive colonialist structures in the engineering world. Consequently, the culture of engineering lacks the critical lense to question authority to assure success in hierarchical institutions such as the military or most corporate organizations [9] .

[11]: Alvares, *3. Science, colonialism and violence: A luddite view*, `https://archive.unu.edu/unupress/unupbooks/uu05se/uu05se07.htm`;

[9]: Riley (2005), *Engineering and Social Justice*;

This entangled web of interests and unconscious mental models complicates the process of understanding humanity's challenges. While we can see the tip of the iceberg of challenges (climate change, social injustice), we are less familiar with the greater structure that gave rise to the symptoms of deeply embedded systemic dynamics.

We believe that the engineering profession has to liberate itself from the authoritarian structures held in place by white supremacist thinking and colonialism. We argue that engineering is not a discipline in itself. It is a trans-disciplinary discourse and solution-creation process that engages with the issues of our current time, the foreseeable future, and all the sciences. It requires critical thinking, contextualization, reflection, and political perspective. All problems only exist within the theories and patterns seen and observed by the critical thinker. Therefore, engineering can be a creative process that welcomes a car's suspension design as much as an interactive art installation if the solution-creation is an answer to a problem within the paradigms of the creator. However, seeing and sensing our whole reality is a profound process that asks for a broad-minded, holistic approach to our environment and ourselves. When a student attempts to go a step further and consider solution creation, the engineering student might be better off in a philosophy class than in a lecture on modeling as the solution creation should not immediately be informed by previously learned technical or traditional knowledge but by a thought process that implements values and sees the larger system.

Therefore, engineering is not obligatorily technical or quantitative. It seeks to make use of our collective creative potential in our social fields to sense emerging changes and future opportunities. Within these social fields, it seeks to bring forth change in a successful manner that makes efficient use of our resources. Oftentimes, the latter part of the process involves quantitative analysis and in-depth technological knowledge, which is only a small part of the engineering journey. In other words, engineers are not machines that make what they are told to make, but sensitive, aware beings that sense emerging opportunities and act upon them in co-creative processes. This is not to say that engineers do not need technical knowledge and quantitative reasoning. In an inter(net)-connected world, many solutions involve the use of technology, and it is wise to familiarize students with a specific set of technological means that allow them to know when they do not know. Students that create technological systems without the needed expertise will create machines that hurt others, fall apart, waste resources, and eventually hurt the planet.

While we are contemplating the nature of engineering, we want to explore the meaning of our general goal: a thriving existence for all. In the state of thriving, organisms grow and flourish beyond mere survival. We understand "thriving for all" as a state in which all living entities have equal access to the material and social/relational conditions to develop their talents or capacities to live up to their fullest potential [12, 13] . Various interconnected terms such as well-being, happiness, welfare, flourishing, describe a similar state. In particular, Wright's (2013) understanding of flourishing as a concept that does not privilege one form of thriving over another one inspired our vision [12]. We would add to this that "all" are not limited to humans but all living systems (rainforests, plants, insects) as humanity is contextualized in earth's eco-systems. All living systems develop capacities and thus have needs.

[12]: Wright (2013), 'Transforming Capitalism through Real Utopias';
[13]: Scharmer et al. (2015), 'Theory U: From Ego-system to Eco-system Economies';

The concept of social justice embraces access to basic material and social conditions for all. In the context of humans, material conditions broadly refer to economic resources for our material needs as well as personal safety and shelter. In the larger context of living systems, nutrients or rivers are examples for material conditions for eco-systems or plants. While the access to material conditions seems more clearly defined, the access to social conditions is a more entangled idea. Social conditions include such things as social respect, community, trust, and solidarity. Social exclusion due to race, gender, ethnicity, sexual orientation, etc. requires specific attention when critiquing the status quo regarding social conditions. If social conditions are met, human beings are treated fairly by the systems they encounter so as to make it possible for them people to meet their full potential. The idea of animal or plant rights for specific social conditions is a contentious topic to be discussed later. Lastly, the idea of sustainability hovers over the concept of thriving or flourishing for all as a justice principle for all beings in the future [12]. It brings our attention to the never ending process of preservation and improvement of the life supporting systems on earth [14] . It further recognizes the interdependence of our human existence on biological support systems such as the carbon cycle. This never ending process is to be contrasted with the idea that sustainable engineering projects could possibly have a project end.

[14]: Hjorth et al. (2006), 'Navigating towards sustainable development: A system dynamics approach';

2.2 Why do we need a shift?

I - Current time's disconnects

Our world seems to bring forth a future that harms living systems and is undesirable from an ecological, social, and spiritual perspective. To give a few examples, humanity uses earth's limited resources 1.5 times faster than its regeneration capacity can handle [13]. Economic science and nation states pursue an unlimited growth imperative with a fatal focus on GDP and false paradigms such as "balanced growth" [5] . 50 percent unsustainable resource consumption seems small when compared to nation states with a large consumption and industry sector such as the United States. The US consumes resources five times faster than earth can regenerate [15] .

[5]: Raworth (2018), *Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist*;

[15]: Scharmer (2018), *The Essentials of Theory U: Core Principles and Applications*;

The worldwide social system has led to an obscene social disconnect that drives fragmentation, alienation, and inequality. This disconnect is mainly driven by unequal distribution of income and wealth. The richest 1 percent of people on our planet own more than the bottom 90 percent, leaving many people in poverty [13] .

[13]: Scharmer et al. (2015), 'Theory U: From Ego-system to Eco-system Economies';

In this time of incredible wealth acquisition, earth's population is paradoxically in a huge spiritual crisis that leads to unhappy livelihoods and individuals becoming disconnected from the whole. Modern psychotherapy tries to support on an individual basis. The therapeutic culture that developed in the 20th century was strongly organized around individual health and not around well being with others [16] . Educational institutions that provide a home to their students do not have a mentorship model found in many religions to strengthen the relational aspect of the scholar-teacher relationship. The worldwide statistic of suicides is one indicator of low wellness across the globe. 800,000 people commit suicide per year, and suicide is the third leading cause of death in 15-19 year olds worldwide [17] .

[16]: Lasch (1991), *The Culture of Narcissism: American Life in an Age of Diminishing Expectations*;

[17]: WHO, *Suicide*, `https://www.who.int/news-room/fact-sheets/detail/suicide`;

We further tend to respond to the mentioned disconnects with technological quick fixes that function as bandaids: they address the arising symptoms but neglect to seek systemic change. The disruption caused by the COVID-19 pandemic tested our collective resilience and unveiled the lack of safety and support systems. Financial pandemic aid programs might have been useful to address monetary shortages but did not change the underlying structures that lead to poverty and extremely high fatality rates of marginalized groups. The vaccination program is a technological quick fix that alleviates some of the present stresses. However, "going back to normal" is an irresponsible desire that ignores the demand for systemic change that this pandemic unveiled.

II - The path of the reductionist sciences

Below, we will dive into a historical description of the development and emergence of modern scientific thought and method. This development has steered itself away from an all-embracing, interconnected perspective to one that reduces phenomena to their basic parts and assumes a separation between the mind and matter. I believe that this historical journey is of interest for us to comprehend how the Western world has reached a point of highly-specialized scientific fields that lack the awareness and ability to prevent harm to the organism we live on.

In the early stages of Greek philosophy, philosophers such Aristotle differentiated between the study of matter and the study of patterns. The study of matter, often described as atomistic, observes the fundamental building blocks of matter by measuring and quantifying it. The inquiry of patterns brings forth insights of self-organization and relationships between things [18] . In the fourth century BC, Aristotle synthesized and explored a wide range of disciplines. His works became the foundation for the Western sciences. Thomas Aquinas (1225-1274) integrated Aristotle's works into the medieval Christian teachings. Based on Aquinas' integration in the 13th century, he left behind a scientific landscape in which every contradiction against the Bible or his integration of Aristotle's works could be seen as heresy. This created an inevitable conflict between the sciences and religion [18] .

[18]: Capra (2016), *The Systems View of Life*;

[18]: Capra (2016), *The Systems View of Life*;

The following time of the Renaissance in the 15th - 16th century challenged the paradigm to understand human nature from a religious point of view. During this time, Leonardo da Vinci (1452-1519) systematically observed nature, and reasoned with shapes, drawing, and mathematics. His practices can be described as a science of qualities and living forms. He pursued an observant, visual study of nature that paid great attention to the processes, qualities, and relationships. A century later, Galileo Galilei (1564-1642) shaped the dogma that nature should be described mathematically, limiting scientists to study properties of material bodies that can be measured and quantified. He considered properties like color, smell, and especially beauty as a subjective mental projection [18].

Galileo is often described to be the first modern researcher and scientist. Whether one sees Leonardo or Galileo as the first modern scientist depends on if the understanding of science is purely built on a quantitative analysis of properties or a discipline that goes beyond measurable properties, instead paying attention to patterns and qualities of nature. Galileo's numerical approach to nature led to revolutionary insights in physics and astronomy, solidifying a mechanistic world view and further suppressing an organic perspective.

René Descartes (1596-1650) deepened this divide by grounding his philosophy in the assumption that mind and matter are separate and independent from each other. The physical world including our living organism was a machine to him (Capra 2014). The assumption was that a system could be fully understood by analyzing its parts and their effect on each other. Isaac Newton (1742-1727) crowned Galileo's and Descartes' mechanistic worldview with his book "Mathematical Principles of Natural Philosophy". In the Western world, the groundbreaking technological insights derived from Newtonian mechanics induced the widely accepted dogma that biological laws can be reduced to those of physics and chemistry. In the 20th century, the discovery of the DNA and the invention of the computer and internet have further strengthened the collective faith in reductionist practices [18].

This short historic summary directs our attention to the scientific method. It is not commensurate with our reality. I argue that science and technology are inherently violent forms of handling the world. The scientific method excludes compassion and distances itself from values. If science and its discovery method exclude values and compassion, it logically follows that the teaching of this science will lack compassion and critical thinking.

The Indian scholar Claude Alvares argues that Western scientific thinking is intrinsically violent, in its historic roots and its methodology. He defines violence as physical and mental harm to living organisms. The earth is by far the largest organism attacked by our scientific and technological advances [11] . Hydro-electric dams, for instance, are an allegedly sustainable electricity source. Often, however, they are an intrusion into the eco-system and harm living systems downstream [19] Furthermore, Colonialism has 'blood relations' to science and specifically the scientific method. Science and technology are colonizing activities. Even nations that are not at war are economically at war. Industrial processes exploit the world-wide colonialist structures and are almost always at variance with life processes and with natural events [11]. Claude Alvares argues that it is impossible to replace the metaphysical core Galilean positivism and the colonialist roots of the Western scientific thinking without the death of science as we know it. Because science cannot be dissociated from its structure of violence, it is not possible to delink science and technology from colonialism without a major unlearning [11]. In section 2, a renewed science of holism, we argue that a holistic view and education that pays attention to the interconnectedness of all beings is necessary to inform this unlearning process, change our paradigms, and provide inspirations for a new collective discovery process.

[11]: Alvares, *3. Science, colonialism and violence: A luddite view*, `https://archive.unu.edu/unupress/unupbooks/uu05se/uu05se07.htm`;

[19]: Jazeera, *Could mega-dams kill the mighty River Nile? (an interactive report) | Al Jazeera English*, `https://interactive.aljazeera.com/aje/2020/saving-the-nile/index.html`;

III - Overcoming the receiving model

Embedded in our modern reality of transactional relationships and exchange, students and technology end-users are mostly on the receiving end. Throughout their day, students receive a defined set of knowledge, food, shelter, warm water, IT, and technology that is brought to them by their administration's judgement. Third party companies are hired to design the buildings, cook and clean for students, install the heating system, and integrate an electricity system, among many other things. It is quite ironic that engineering education puts a strong emphasis on management and systems design but students do not engage with the very systems that keep them warm, safe, well-fed, and technologically up-to-date. In transaction for these services, students pay tuition to their college. This model, however, is only a creation of the capitalistic paradigm of transaction. A relational model could overcome the passiveness of the receiving model and create communities that engage in a creative process to build their community.

Transactional relationships are relationships that are defined by the exchange between people. They are to be contrasted with relational relationships, which concern the ways people are connected with each other

Most of our digital infrastructure and communication systems have emerged in the last decade. They are developed by companies that established a one-dimensional relationship between the supplier and the user. Companies develop digital features or products on their own and rarely ask for input or offer democratic systems for co-creation. How do we design technology that invites the user to participate in building and maintaining the system? Such engineering work would create containers for co-creation rather than to offer a fixed set of products to the user. Examples for co-creative systems are the Wikipedia platform or the Linux operating system. As most digital systems are changing fast and are completely new to us, there is an urgent responsibility to start to develop engineered systems that are life-giving to a free and fair co-creative process. The Billion Seconds Institute, for instance, strives to transition from individualistic user-centric digital economy to digital eco-system shaped by its interconnected citizens, intercitizens [20] . Similar to how fruits and vegetables have become bigger and more nutritious because humans and animals creatively shaped them, our technology should be shaped by how we interact with it to suit our needs better.

[20]: , *The Billion Seconds Institute*, https://billion.iam-internet.com/;

This idea can be extended to the academic world which lives in a digital framework. The academic dialogue mostly happens in journals or at conferences, however. Many papers are inaccessible behind paywalls, and locations of scientific dialogue are scattered all over the internet. Only contributions that are associated with institutions are taken into consideration. Some of these reputational expectations might have their validity. However, we see opportunity for a more active technological creation process of the concepts and knowledge that inspires us and organizes our world.

Holistic Science as the Foundation for a Critical Engineering Practice

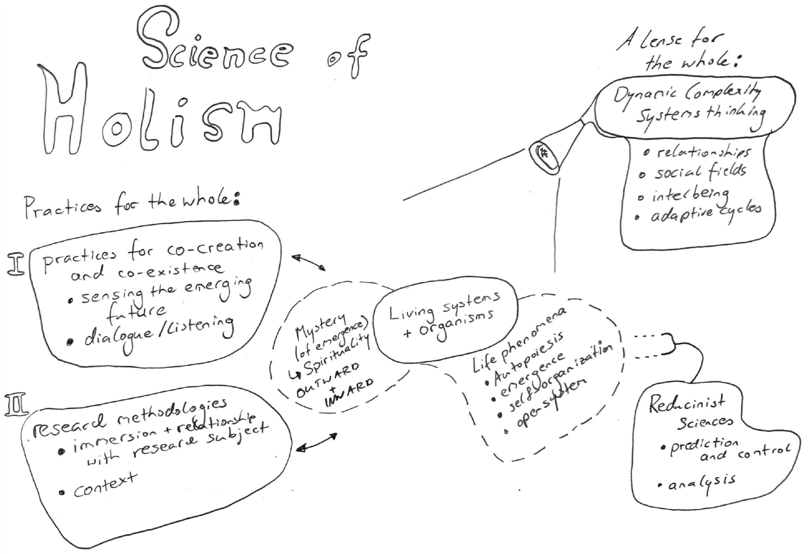

Figure 3.1: Web-nodes of a holistic science with living systems at the center and dynamic complexity thinking as a lens for the whole. All nodes depicted in the illustration can be found in the table of contents below.

3 A Renewed Science of Holism

A renewed science of holism has the potential to challenge our paradigms and create social, environmental, and political health [21] . We use the word renewed to emphasize that past epistemologies and schools of thoughts approached the study of nature holistically. They saw the cosmos as an organism that was defined by its relationships rather than only its substance. Therefore, the recurring science of holism sees the reductionist sciences and their insights as a subset of knowledge that comes in handy once we deal with non-living systems.

We see living systems or large-scale organisms at the center of a holistic science. Life phenomena describe specific properties of life such as autopoiesis, self-organization, and emergence. The mystery of emergence in our universe makes spirituality an inherent part of life, and therefore an inherent part of a science of holism.

With life at the center, we need a lens to make sense of the whole reality. The field of dynamic complexity or systems thinking takes on the big challenge to understand living systems. Systems thinking attempts to create one whole trans-discipline that interconnects all disciplines.

We further believe that practices that are commensurate with the nature of reality are crucial for an effective engagement with living systems. Such practices include (I) methods for a co-creation of the future and (II) research and learning methods that embrace unpredictable emergence of insights and emancipate us from hidden oppressive power structures. Lastly, the reductionist sciences are still a part of a holistic science. They are useful for analyzing, predicting, and controlling non-living, un-complex systems.

[21]: Vanasupa and Barabino (2021), 'An engineering education of holism: Einsteinimperative in Insights Into Global Engineering Education After the Birth of Industry 5.0';

It is not the purpose of a holistic science to offer direct answers or solutions because it is impossible to pinpoint specific means or goals in an ever-changing, non-linear, complex world [14] . By referring to the following concepts and ideas, we hope to introduce you to a renewed science of holism to change paradigms in the engineering field. After Donella Meadows, the change of paradigms or mindsets is the most significant leverage point for intervention in a system and informs lower places for intervention such as policies, goals, or information flow [22] . Life is a web and not a linear list. We therefore acknowledge that the following list is an inevitable simplification and subject to alterations, changes. There is no hierarchy or order among the various points. They all inform each other, and it is this very integrative discovery process that we hope to elicit. Every person is free to interconnect learnings from all fields to create their own deeper connections and meanings.

[14]: Hjorth et al. (2006), 'Navigating towards sustainable development: A system dynamics approach';

[22]: Meadows, *Leverage Points: Places to Intervene in a System - The Donella Meadows Project*, http://donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/;

3.1 Phenomena around life and their teachings about reality

As the so-called industrialized world and especially the engineering world finds itself to be a threat to our life-giving systems, we developed the premise that drawing inspiration from things that are alive will help us to develop intentions and even technology. Philosophically put, for working toward a better future, we as an earth-bound species should let ourselves inspire by Earth and its phenomena that have allowed us humans and so many other beings to thrive. Learning from the processes, eco-systems, and natural forms in nature can be summed in the word biomimicry. Some of the major phenomena around life are that life is conducive to other life, that life is interconnected and defined by its relationships, that life re-creates itself from within, and that it is self-organizing and resilient. Furthermore, living systems are emergent, recursive, and they show self-organized actions inside of fields. These living qualities are quite distinct from the time-independent, static behavior of the objects of reductionist science; therefore knowing how to work with them calls for scientific methods that are equally distinct from reductionist science methods.

The chemist Ilya Prigogine demonstrated that amino acids, which we know to be the molecules of living organisms, spontaneously emerge from the presumably inorganic chemicals when the conditions are far from equilibrium [23] . This discovery, for which he won the Nobel Prize, demonstrated the unpredictable emergence of order from chaos, a spontaneous state change in the far from equilibrium regime. This far from equilibrium regime, the regime of living matter, is one for which the simple models of reductionist science do not apply. We are left to observe and learn from nature's methods.

[23]: Prigogine et al. (1963), 'Introduction to thermodynamics of irreversible processes';

Becoming nature's apprentice by observing phenomena is deeply inspiring in understanding what it means to be an interconnected living being. They are a holistic guide that allows us to sharpen our vision and goals when taking action in this world. For instance, we can ask ourselves as a part of a family or as an engineer if we are conducive to life or life-giving in the ways we shape our world. Are my contributions as a parent or project manager creating conditions that strengthen our field of relationships? Are our relationships aligned with the shared commitment that binds us? Is my design adaptive to account for emergence or able to adapt to what I have not accounted for? If we strive to be good living beings, we should be ourselves conducive to life, value the relational context, and create conditions that favor outcomes of thriving, fairness, and freedom. Therefore, the models we use as engineers to make sense of our world need to reflect this reality.

Autopoiesis

In the Western scientific world, the phenomenon of life is often tackled with a list of essential features that living beings exhibit. In traditional biology, homeostasis, organization, metabolism, growth, adaption, response to stimuli, and reproduction are among the commonly identified features of living beings. The line between non-living and living matter is quite blurry. From a systems perspective, life is identified as a self-organizing and autopoietic entity. The word autopoiesis refers to a system that is capable of reproducing and maintaining itself. If we compare swarm robots, artificial intelligence, and factories with plants, humans, or cells, a common shared feature among the living is that they can take care of themselves. Autonomous cars are capable of executing complex, 'smart' behavior, but they lack the ability to maintain themselves. The word autopoiesis is a combination of the Old Greek words o- (auto-), and (poiesis) meaning self-production. In that sense, we could consider a robot living if it were able to repair itself, create new robot pieces, and reproduce itself in some form. But instead of fantasizing about scary technological developments, let us dive deeper into the phenomenon of autopoiesis that we find everywhere in life. Please note that my intent is not to justify a definition of life as autopoietic but to point out the occurrence of autopoiesis in life.

Autopoietic systems are often nested and occur on many levels. Logically speaking, this makes sense because autopoietic systems recreate themselves. They are like recursive code, and therefore, an autopoietic system will reproduce an autopoietic system. That is quite abstract but becomes more tangible if we look at living systems familiar to us.

Cells are autopoietic systems. They are able to reproduce themselves and defend their identity. A heart cell will defend its shape and characteristics to stay a heart cell. A heart cell might eventually split in half and recreate itself. Several heart cells will do everything to stay in heart-shape. Similarly, the seed of a tree will grow a tree that will eventually recreate the seed. An animal or human is consequently a larger autopoietic system of many nested autopoietic systems.

The autopoietic view on life shines a light on the living, re-producing nature of systems that we create. A factory for airplanes, for instance, is an allopoietic system at first. The airplane factory and the machines in the airplane factory clearly produce something that is distinct from the producing elements. However, as soon as we include the factory's supply chains, the workers, mangagers, customers, investors, competitors into the total viable system, we can consider this system to be autopoietic [24] . The larger system will strive to stay existent and re-create itself.

[24]: Koskinen (2013), 'Processual autopoietic knowledge production in organizations';

It is the phenomenon of patterns patterning. The effect of autopoiesis can be seen in reductionist science. Reductionist science's fundamental action is to fragment the whole to a simple unit of analysis. As a result, such science recreates itself by fragmenting us in our thoughts and beings, alienating us from meaningful connection with our whole selves. I claim that such patterns of recreation can be observed in our thoughts as well as in the ways institutions sprout from the seed of fragmentation. As an autopoietic sociopolitical system, institutions will naturally tend to reproduce themselves and stabilize their existing power structures. Even an educational institution that organizes itself around understanding students' needs and visions will undermine its own aims through the dynamics of its many unexamined thought structures. As a specific example, consider employing the scientific method for this purpose. Such a method is fit for the purpose of working with non-living objects; it is not fit for understanding a human system. As discussed later in the chapter on research methods the scientific method treats the point of research, in this case students, as objects, held separate from and unaffected by the observer subject. Consequently, any result that assumes students are "objects" inherently denies students' actual state of being as they are thinking and feeling entities with conscious minds.

Autopoiesis allows us to understand information flows in systems and see characteristics that are hidden to us. For us humans, an awareness of the phenomenon of autopoiesis can build the system's capacity to sense and see itself. The life force is in our systems as much as it is in our cells. White supremacy and other systems that resulted from colonialism are contemporary examples of reproductive systems that make the fight for systemic justice so hard. The Western capitalist system, majorly based on power-structures from colonialism, is a reproducing organism that resists change due to the power structures created by the very people that create and live in the system. Therefore, autopoiesis is a tool to understand the difficulty of systemic change.

On a personal level, the phenomenon of autopsies teaches us that we as humans, as our own organism, are naturally concerned with self-maintenance. If self-maintenance or self-care are a core ability of every organism, a holistic science should cultivate our ability to practice self care.

Interconnectedness

If we look at a living being such as an apple tree, we can observe its leaves, roots, branches, and many other parts of it. However, the tree has her roots dug deep into the soil, from which she derives nutrients. The soil holds moisture from the rainfalls and rivers. And the apple tree would not grow any apples without the bees, wasps, and flies that pollinate the flowers. We can observe that a tree is so much more than her parts. She is defined by the numerous relationships with other things around it, deeply interconnected with its environment. Specific behavior between the parts of the system is due to the underlying structure of the system. In the field of relationships, structures condition behavior. The root tree's root structure enables her to pull in the nutrients from the ground, against the gravitational field.

In order to understand the systems of life we need to pay attention to the fields of relationships and their quality. This relational model shifts our focus from looking at the transaction between things to the relationships between things. The interconnectedness of matter and not only animate matter has come up in a phenomenon observed in quantum physics called quantum entanglement. Quantum entanglement provides strong support for the interconnectedness of matter on a reductionist level and defies all laws of classical physics. Physicists have shown strong support for matter or particles that are inextricably linked no matter the distance between them [25] .

[25]: (), *Light from ancient quasars helps confirm quantum entanglement | MIT News | Massachusetts Institute of Technology*;

We will provide another example for an interconnected world on a reductionist level that is quite contentious but thought provoking. Quantum indeterminate electronic random number generators were placed all around the world. These machines generated random numbers with maximal entropy. Measurable deviation of statistical distribution parameters were observed during major world events including the attacks on September 11th. The hypothesis is quite bold but suggests the possibility that the measured correlations were attributable to the consciousness attendant to global events [26] .

[26]: Nelson et al. (2002), 'Correlations of continuous random data with major world events';

Self-organization

In natural systems, some form of order in space and time will emerge naturally. Orders exist on different levels and can be described as hierarchies. In this context, hierarchy does not refer to a form of control over the lower sections; it refers to shared dimensions of scale, such as time and space. Every level of the hierarchy functions semi-autonomously [27] . Larger, longer-existing levels conserve and stabilize conditions for the smaller and faster levels. As the smaller (or 'lower' levels) produce beneficial results from their innovation, this 'knowledge' is fed upward in the hierarchy; one can view this as systemic adaptation. Every level goes through its own cycle of conservation of resources and innovation. Therefore, natural systems are adaptive on many levels. The emergence of novelty happens on all scales; the whole is fractal in nature.

[27]: Holling (2001), 'Understanding the Complexity of Economic, Ecological, and Social Systems';

Natural systems cycle between the emergence of innovative things and the conservation of resources. They are creative and conserving at the same time. Over time, natural systems adapt and restructure themselves to create a flourishing web of life. New species will emerge to generate and test innovations. Natural systems show us how to adapt to changes, create novelty, and conserve energy. They are in a constant adaptive cycle that goes through stages of creation and conservation. However, these cycles can be inhibited when not correctly understood. Our social systems are also natural systems. Social systems are given to systemic "traps," such as a poverty trap in which resources are locked in a part of the system, disabling the natural cycle of systemic change [27] . Only when adaptive cycles work on many levels of the hierarchy, can the system adapt and create new opportunities. In the section "adaptive cycles," we will take a closer look at important system properties regarding adaptive cycles, poverty and rigidity traps that keep a system from progressing.

[27]: Holling (2001), 'Understanding the Complexity of Economic, Ecological, and Social Systems'; p. 400

Life is conducive to life

We can observe a life force on all living beings. This life force does not only consider the individual living being but extends outward to their environment. All well-adapted organisms have learned how to create life-favoring conditions, for there is no other option. Janine Benyus calls it "a rite of passage for any organism that manages to fit in here over the long haul" [1] . As humans are part of and depend on the earth-organism, we cannot exclude ourselves from this practice. Living beings will create conditions that are conducive to life, ensuring that they and their future generations can come back to a hospitable place. If we as humans want to create a hospitable place on this planet for future generations, we will have to relearn from nature how to create opportunities rather than destruction and waste.

[1]: Benyus (2002), *Biomimicry: Innovation Inspired by Nature*;

That life creates conditions conducive to life is a profound realization. It means that living beings exist in reciprocity with their environment, raising life. In its essence, this phenomenon is the most obvious when mothers or parents raise their children. In these moments, they devote their existence to creating life-bringing conditions. However, do we stop being motherly after our child has reached a certain stage of independence? Robin Kimmerer describes mothering as the building of "a net of living threads to lovingly encompass what it cannot possibly hold, what will eventually move through it" [28] .

[28]: Kimmerer (2015), *Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge and the Teachings of Plants*;

We can call the radiation of life energy from living beings to other beings love. We are using the word love not as an object that we possess and can give to others, but as an act of sustaining attention. The artist Marina Abramovic' demonstrated the power of this sustained attention to liberate others in her 2010 eponymous performance piece, The Artist Is Present [29] . In it, she sat silently across from a museum patron, gazing into their eyes. We can find the out reaching power of love in the beauty of plants in how they take care of us and provide a habitable home.

[29]: MoMA, *Marina Abramović. The Artist Is Present. 2010*, `https://www.moma.org/learn/moma%5C_learning/marina-abramovic-marina-abramovic-the-artist-is-present-2010/`;

We believe we are born whole: enabled for love, life's essence to flow between us. Once socialized into the systemic conditions of violence that we inherited, receiving and giving love is an ability that we have to re-learn and practice in all parts of our lives. Our male-dominated, competitive world has created a collective blind spot for this quality in all living beings. The idea of the "survival of the fittest", often cited as Charles Darwin's works, is quite opposing to love as a quality of life. It is a phrase coined by the economist Herbert Spencer, infused with his interests in economic domination and has falsely shaped our modern scientific evolutionary understanding of life. Darwin was well aware of the evolutionary weakness of the survival-of-the-fittest idea: "Those communities which included the greatest number of the most sympathetic members would flourish best and rear the greatest number of offspring." [30] . Indeed, Charles Darwin mentioned the world love more than 95 times, referred to moral sympathy 92 times, and only wrote "survival of the fittest" twice [31] .

[30]: NBC, *Survival of the Fittest Has Evolved: Try Survival of the Kindest*, `https://www.nbcnews.com/better/relationships/survival-fittest-has-evolved-try-survival-kindest-n730196`;

[31]: The-Darwin-Project, *Darwin's Unfolding Revolution*, `https://www.thedarwinproject.com/revolution/revolution.html`;

As technologists and engineers, we are on a journey to a synthesis of technology and biology. It is the technology of biology that leads us to creating a thriving existence [1] . And love and hospitality for life seem

[1]: Benyus (2002), *Biomimicry: Innovation Inspired by Nature*;

to be a technology of biology that needs to be reflected in the solutions that we create for our world.

3.2 Dynamically complex systems theory

We live in a VUCA world [32] . It is a world defined by volatility, uncertainty, complexity, and ambiguity. While any analysis of the whole will inherently be incomplete, the lens of complex dynamic systems affords us a conceptual understanding and a language to work with our whole VUCA world. The behavior of a complex system is always greater than the sum of its individual parts and has therefore to be studied as a whole or relational field.

[32]: Bennus et al. (1985), 'Leaders: The strategies for taking charge';

We can view dynamically complex systems as involving subsystems and processes that vary in physical size and time. They are open, recursive, organic, nonlinear, and emergent. To comprehend the system as a whole, all parts and processes need to be understood through a synthesis of their multilevel and multi-dimensional interconnections [14] . For instance, to understand climate change and develop solutions, a connection of the fields of chemistry, physics, biology, native wisdoms, psychology, political studies, sociology, and many others is necessary. At the same time, we acknowledge that any point of view, including a complexity lens, is incomplete. However Systems thinking attempts to bridge the gap between all the disciplines, moving to a one trans-discipline that is inspired by non-linear, organic thinking.

[14]: Hjorth et al. (2006), 'Navigating towards sustainable development: A system dynamics approach';

The complexity of living systems makes it impossible to predict the future. However, one can deal with the future through assumptions [14]. This complexity does not emerge from random association from an uncountable amount of factors but from a small set of controlling processes [27] . Through the lens of complex dynamic systems, our world is not random but a complex structure that builds and breaks on itself through recursion, self-organization within force fields; a panarchy.

[27]: Holling (2001), 'Understanding the Complexity of Economic, Ecological, and Social Systems';

One big organism

The trans-disciplinary nature of systems thinking hints at the natural phenomenon that life is a manifestation of interbeing. Separation is an illusion. In the case of humanity, it becomes clear that nature is in humanity and humanity is nature. Deep ecologists follow this thought by intrinsically valuing non-human species and biodiversity. In their eyes, humans are only one of many other species and parts that enable the magic of life. The works by chemist James Lovelock and biologist Lynn Margulis on the so-called Gaia hypothesis, conceptualize our earth as a single interconnected biogeochemical entity, which resembles the idea of deep ecology and systems thinking [33] . Our Western societal systems have yet a long way to go to reflect the deep relationships and interconnectivity on earth. For instance, Western legal systems currently justify the domination of nature by withholding rights to animals and other natural systems. In Germany, animals are treated by the law as if they were objects. Legally speaking, if you run over a cat, you cause damage to property. The animal liberation movement, kicked-off by Peter

[33]: Lovelock et al. (1974), 'Atmospheric homeostasis by and for the biosphere: the gaia hypothesis';

Singer's works, demands rights for animals and emphasizes that the exploitation of animals in factories is similar to prejudice like sexism and racism [9].

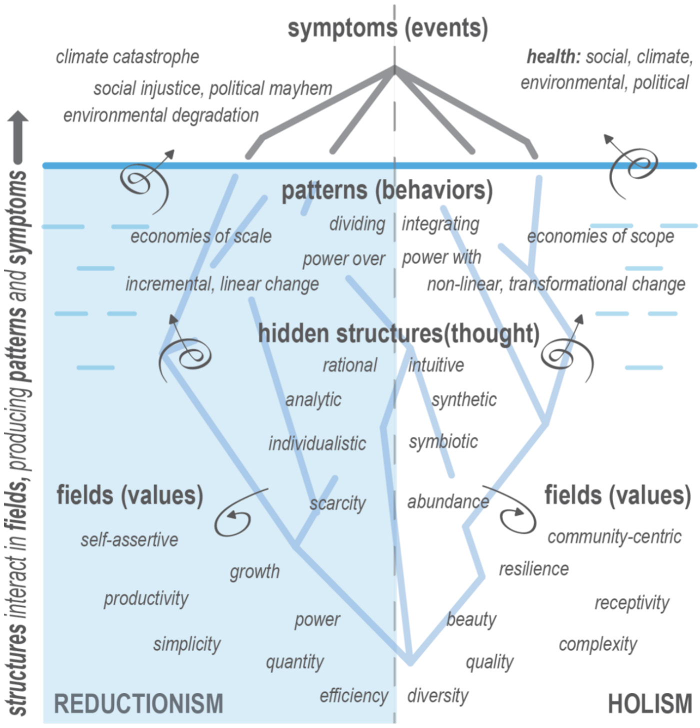

Figure 3.2: Reductionist and holistic values and thoughts that give rise to the tip of the iceberg. While this illustration contrasts reductionism and holism, holism encompasses both sides (Vanasupa and Barabino [21]).

While these thoughts are relatively new to the Western world, holistic thinking and respect for the live-giving systems in nature have been a core of indigenous American cultures. In the province of Quebec, Canada, an indigenous tribe has arrived at a novel legal level of protection for the Magpie River. Since April 2021, the Magpie River has been considered a 'legal person', bringing attention to a movement called 'rights of nature' [34] .

[34]: Jazeera, *This river in Canada is now a legal person*, https://www.aljazeera.com/news/2021/4/3/this-river-in-canada-now-legal-person;

Sustainable development

To develop the conditions for a sustainable world, a shift in the perception of the meaning of sustainability has to occur. It is crucial that researchers and students accept that sustainability is not a project with an end-point, but an unending process that is interconnected with everyday work [14] . In an engineering world, this shift of perception means that a novel renewable energy technology can never be the final solution to our environmental problems. Using a dynamic systems lens, our systemic societal and environmental problems are features of the systems as designed, rather than bugs. Technology alone cannot solve these problems; it is causing them.We need deeper changes that restructure our social and creative fields. Our society is still trying to understand the concept of sustainability, and with this discovery process comes the effort to make tangible what sustainable development means. Sustainability is the capacity to create, test, and maintain the capability to adapt [27] . Most definitions of sustainable development focus on the preservation of specific conditions. In a biophysical sense, this is the preservation

[14]: Hjorth et al. (2006), 'Navigating towards sustainable development: A system dynamics approach';

[27]: Holling (2001), 'Understanding the Complexity of Economic, Ecological, and Social Systems';

and improvement of life supporting systems on earth [35] . This goal is essentially to say that we as humans should be part of the natural phenomenon to create conditions that are conducive to life. We can do so by being attentive to relationships across the system, by understanding force fields and information flows, and by facilitating self-organization.

[35]: Fuwa (1995), 'Defining and Measuring Sustainability: The Biogeophysical Foundation';

Acknowledging oscillatory patterns as a normal part of nature, sustainable development concerns managing, and adapting to the frequencies of the oscillations found in our natural world [36] . To us humans, life might seem slow-paced and stagnant. However, life pulses and oscillates. Our hearts pulse, our habits are repetitive, our earth cycles through the seasons, and our forests grow and burn down in an oscillatory fashion. Due to the ever-swinging nature of life, Holling refers to sustainable development as the goal of fostering adaptive capabilities/cycles and creating opportunities. As the people who engage in a process to sustainably develop our world, it is on us to understand the structures, relationships, and cycles in a system. Thus, engineering cannot merely focus on sustainable technology. Sustainability has to be conceived as an all-embracing concept that brings ecological as well as social systems into the circle. I believe engineers can only do good to the world if we open up our goals and visions to those of community development. Community development is an inherently political activity committed to environmental sustainability and social justice [4] . Sustainability and social justice are necessary conditions for a human existence of thriving and require a political, well-informed stance on the side of the change-maker. In other words, in order to thrive, humans must have what is rightfully theirs and must be treated fairly by the system.

[36]: Odum (1994), 'The energy of natural capital';

[4]: Ledwith (2017), 'Emancipatory action research as a critical living praxis: from dominant narratives to counternarrative';

System dynamics

Making sense of the changes and relationships in living systems can be overwhelming. In the world of systems thinking, adaptive cycles explain the release and conservation of energy in ecosystems and social systems. Causal loop diagrams are a helpful tool to visualize the relationships in a system. We can observe cyclical change in all living systems. Oftentimes, change comes as a form of disruption. If we seek to design systems for a thriving existence, we need to make sure that the networks in our systems have enough resiliency to exist through phases of disruption and enough adaptability and creativity to change when necessary. The assessment for a need of action or for the well-being of the system is the very center of examining the quality of any system. When are we happy with the achievements of the system, and when do we need to change our course of action to create a more sustainable system? The aim of systems thinking is not to establish an exact definition of the problem to find a methodology to solve the problem. "Rather, it is to reveal the particular strengths and weaknesses of available systems approaches and to make explicit the consequences.. of using any of these" [37] .

[37]: Jackson (1990), 'Beyond a system of systems methodologies';

Before we dive into concepts of change in living systems and forms of visualizing relationships, I want to introduce the concept of Doughnut Economics to assess the performance of a system. Many times we mentioned our aspiration to work toward a thriving existence for everyone. However, this is still very abstract as a vision for the 21st century. We are in need of a framework that tells us in which areas we need to work harder to achieve a social foundation for everyone. Development programs across the globe used the gross domestic product (GDP) as an indicator for national well-being. However, unlimited growth is an inappropriate measure for an earthbound species living on a world with limited resources. In order to create responsible systems, we need to know when and where we reach the limits of human activity on this planet. The Doughnut by Kate Raworth is an economic concept that offers a compass for navigating through the 21st century. The "safe and just space for humanity" lies in between our planet's ecological ceiling and a social foundation [5] . The theory is that if we successfully navigated ourselves in between these two boundaries, we could ensure well-being for every human and preserve the life-giving systems on our planet.

[5]: Raworth (2018), *Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist*;

Human existence has shaped our planet. Our current geological epoch is the anthropocene, an epoch characterized by the effects of human activity on our planet. For the last 12,000 years, earth's temperature has been far more stable than before. During this time of climate stability, agriculture and first great human civilizations emerged. This steady climate phase is called Holocene and has given us the best conditions on earth we have ever had. Science suggests that this phase will continue for another 50,000 years due to an unusual path that Earth is currently making of the sun [5]. However, human activity is pushing the boundaries of this climate sweet spot.

To sustain these amazing live-giving conditions, we need to have an awareness of our planetary boundaries. Johan Rockström and Will Steffen identified nine critical processes on our planet that regulate Earth's ability to stay in the Holocone equilibrium. These nine planetary boundaries build the ecological ceiling of the Doughnut compass. Humanity needs to minimize its effects on climate change, ocean acidification, chemical pollution, nitrogen and phosphorus lading, freshwater withdrawals, land conversion, biodiversity loss, air pollution, and ozone layer depletion to maintain Holocene-like conditions [38].

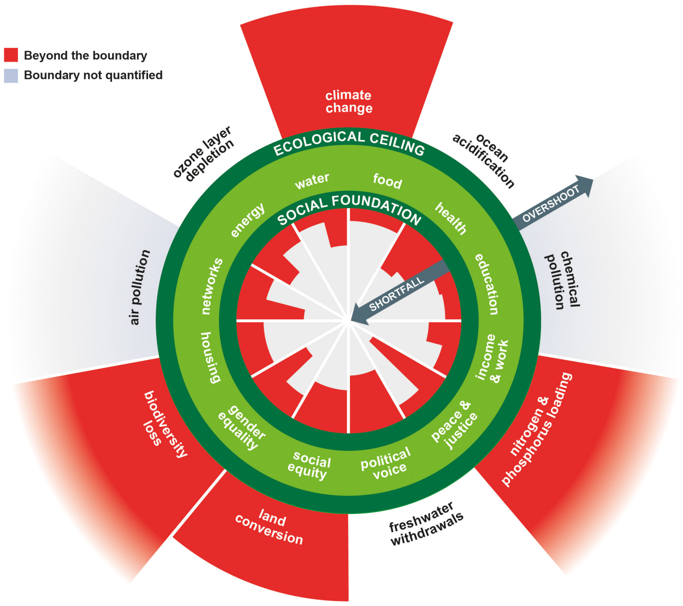

Figure 3.3: The Doughnut after Kate Raworth [5]. The outer red sections illustrate humanity's violation of our planetary boundaries. The inner red sections refer to the fraction of humanity that is left behind with their basic needs.

While human activity has pushed the ecological ceiling, human thriving is only possible if all humans on this planet can lead their lives with dignity, opportunity, and community. Raworth captures this foundation for well-being in the access to food, health, education, income and work, peace and justice, political voice, social equity, gender equality, housing, networks, energy, and water [5].

Adaptive cycles and panarchy

All natural complex systems are defined by two properties: stability and change. A system forms a panarchy when it can create opportunities while staying safe from disruption and destabilization. The analysis of cycles in a panarchy that lead to novelty and stability helps us to investigate the meaning of sustainable development.

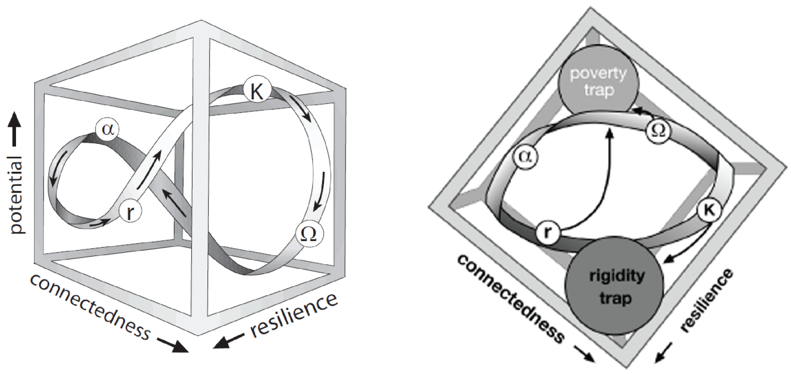

Figure 3.4: The left graphic depicts the three-dimensional adaptive cycle with the three relevant axes that define a system. The right image shows systemic traps that disable the natural cycle of systemic change and innovation [27].

In complex systems, a form of order or hierarchy emerges in time and space. Hierarchies in natural systems are not a top-down control assertion. Semi-autonomous levels form and adapt within a hierarchy and vary in their time span of occurence and physical scale. Larger, longer-existing levels conserve and stabilize conditions for the smaller and faster levels [27] . Every hierarchical level embarks on its own adaptive cycle to generate and test innovations. After Holling, three main system properties shape the course through the adaptive cycle: (1) the system's inherent potential, (2) the system's internal controllability, and (3) the system's adaptive capacity. The inherent potential can also be called wealth of a system. It is its potential to create opportunities in the parts of the system that are available for change [27]. The second property, the internal controllability, is a measure of the systems rigidity or flexibility. It determines to which extent a system can control its own destiny by passing on information and being sensitive to stimuli. It refers to the connectedness of the system Adaptive capacity, the third property, is the system's resilience to unpredictable shocks.

[27]: Holling (2001), 'Understanding the Complexity of Economic, Ecological, and Social Systems';

All levels of a system's hierarchy cycle through phases that show varying degrees of system potential, connectedness, and resilience. The adaptive cycle by Holling alternates between slow accumulation and transformation and faster, shorter spurts of release of energy. It is a three-dimensional figure eight that cycles from conservation to release to reorganization to exploitation and back to conservation. Oftentimes, the conservation of resources is broken by a disruption of the system. It is in the times of release of energy and the following reorganization process when innovation occurs. In the times of disruption, the cost of failed attempts is lower and the system is inherently more creative. Once the disruption is settled, only the most successful innovation will survive in the system and finally receive most of the resource flows. At this point, the system finds itself back in a mode of conservation [27].

Holling argues that sustainable development is the "goal of fostering adaptive capabilities while simultaneously creating opportunities."

The management of living systems is complicated. Especially in human systems, insights lead to interventions that accumulate over time. Bureaucratic systems are a good example of intervention to streamline connectedness and pass on wisdom from the past. However, if a system is poorly set up, it can find itself in a poverty trap or rigidity trap. An adaptive cycle collapses and creates a poverty trap when the system is in a state of low connectedness, low potential, and low resilience. A rigidity trap brings an adaptive cycle to stop when the system has high potential, high connectedness, and high resilience [27] . The system is too resilient to any form of change or disruption to release conserved capital. Therefore, no major innovation occurs. From rigidity traps we can learn that high resiliency creates a numbness to disruption and therefore suppresses creativity.

[27]: Holling (2001), 'Understanding the Complexity of Economic, Ecological, and Social Systems';

While Holling's adaptive cycles seem abstract, they teach us about the states, through which any natural system moves. They teach us that disturbance and reorganization are natural parts of a cycle of any living system. And only when we create social systems that allow themselves to tear down old structures, offer up resources, and watch the game of emergence and restructuring, can we look comfortably into a future of stability and opportunity.

Structure conditions behavior

One of the central tenets of systems thinking is that structure conditions behavior; hidden structures are the most influential because one cannot alter something that cannot be seen. Causal loop diagrams enable us to see these unseen structures and to include information flows and relationships. Causal loop diagrams are a visual tool for mapping out complex relationships rather than the properties of every component. They can be used as a tool for a personal inquiry of our inner world as well as a tool for discovering nets of interconnectivity around us. As an externalized map of the dynamics, they also enable us to consider points of intervention and points of leverage for systemic change [22] . The information links in a system define how we perceive a task or event. For instance, to create solutions for a demotivated, frustrated work force in a company, one has to look at the data, goals, incentives, costs, and feedback that motivate or prevent a certain behavior. The same people and institutions will work completely differently if feedback loops and information flows are rerouted to guarantee transparency and freedom in action [14] .

[22]: Meadows, *Leverage Points: Places to Intervene in a System - The Donella Meadows Project*, `http://donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/`;

[14]: Hjorth et al. (2006), 'Navigating towards sustainable development: A system dynamics approach';

Systems thinking refers to the act of changing information flows as changing structure. Changing structure is powerful for managing a system because it decreases our fixation on individuals and brings the design of the system into the center of attention. It further teaches us that dysfunctional system design is not a flaw of the organization but a result of the thought patterns, from which the system structure emerged. It redirects our attention to the hidden invisible forces that control the system without pin pointing nodes or people.

3.3 Methodologies to learn about our world that are commensurate with the nature of reality

The reductionist sciences seek to learn about our human world by the means of the scientific method. As discussed, the legacy scientific method is analytical, meaning it fragments the whole into simpler, analyzable parts. Scientists formulate a hypothesis that is tested through experiments on the research object. The researcher is an external investigator that assumes they are separate from and independent of the objects of inquiry. However, this method is incommensurate with the nature of a living system, so it is unfit to learn in a system involving people, for example. Here are three reasons.

(1) — From a holism perspective, it is incongruent to see the system of interest as external. As we discuss in "Spiritual engagement with ourselves", understanding our inner consciousness as part of the system is a learning process that brings deeper insights to the surface that cannot always be expressed in terms of simple logical conclusions and quantifiable data [15] .

(2) — Research participants are complex beings that require a deep contextualization process in regard to their political, social, economic structures. Equality between the researcher and the participants is necessary to explore these worlds; a treatment that changes the research "object" to a research "subject" [4] .

(3) — Research and learning in a world of complexity is unpredictable and thus needs to invite uniqueness and emergence. Control and predictably, which are required by the scientific method, are out of place.

[15]: Scharmer (2018), *The Essentials of Theory U: Core Principles and Applications*;

[4]: Ledwith (2017), 'Emancipatory action research as a critical living praxis: from dominant narratives to counternarrative';

Emancipatory Action Research

Researchers that seek to learn about living systems in a socio-political context need to take the time to equalize the playing field, reflect on their inner ideas of systems, and immerse themselves with the participants. It is worth noting that any research inquiry takes place in the socio-political environment of the field of research.

Margaret Ledwith coined a research practice called Emancipatory Action Research (EAR). Her practice comes from the understanding that structural power is real, and that predominant narratives in our society feed into a "bigger lie" that persuades us to lead our lives in the interest of the privileged. Emancipatory action research is a critical and participatory methodology of freedom with the intention to dissolve thought structures that self-replicate oppression. Habermas' critical theory adds to the notion that no field of knowledge has full validity in its claims. Every field of knowledge has particular interests and goals which constitute the forms of knowledge obtained. EAR aims to liberate the researcher from the unconscious mental models that invisibly guide their inquiry. It is a form of research that critiques the status quo for the sake of a larger systemic picture that allows us to understand opportunities for intervention. Its specific goal is community development, a political activity committed to social justice and sustainable development [4].

Ledwith argues that we need to cultivate a "critical living praxis" to unite the streams of theory and practice by co-creating knowledge in an equal partnership specifically with marginalized groups. Her intent is to engage in an active process of community development and reveil narratives of people that challenge dominant narratives by inducing participation among all people involved in the practice. The underlying idea for such a practice is a shift in the understanding of the research participant from a research object to a research subject who is seen in context of the political, social, and economic structures of our time (Ledwith 2017, p. 56). EAR strives to have a meaningful impact on social change by extending beyond people and groups to draw a more holistic picture of system structures to develop strategies for intervention in a cyclic fashion [39] .

[39]: Burns (2007), *Systemic action research: A strategy for whole system change*;

From a systems perspective, EAR is more commensurate with reality because it is a deliberately critical process that accounts for our unconscious mental models and seeks to unveil them. It pays close attention to the relationships across the system by establishing a relationship with the participant. It intentionally shifts the goal of inquiry from quantitative analysis to a relational, qualitative engagement to pay attention to the participant's context. In other words, EAR inquires about the force field around the participant. As it embarks on a journey of co-creating knowledge through the practice of listening, teaching and learning, human beings are valued and respected in their full complexity. This practice leads to a larger systemic understanding that reveals insights about the consequences of possible interventions.

Teaching and learning

Teaching and learning in a complex world means to embrace the unpredictable and generative qualities of educational processes. It requires a shift in teachers' mindsets to accept what is unexpected and beyond their control. On a similar note, complexity reminds us to be careful of our assumptions. Those appropriate for simple systems, such as linear thinking, control, and predictability are suited to many cases of working with inanimate matter. They are not suitable for the social and political world [3] .

[3]: Gough (2012), 'Complexity, complexity reduction, and 'methodological borrowing' in educational inquiry';

As our understanding of learning shifts from a linear process to a more volatile, unique experience, we see a need to restructure our understanding of successful learning. There has been an emphasis on measuring educational outcomes and comparing the products of education on national and International levels using the methods of our legacy science. The result is often quantitative measures that do not account for the whole. Complexity invites us to rethink the framework of measurable educational outcomes as education and learning are a process of emergence. In such a process, systemic state changes are spontaneous, rather than produced by the linear delivery of a curriculum. Educational insights and learnings emerge in educational processes in an unpredictable and unique way [3]. We recommend the practice of emancipatory action research to gain insights into the student experience with the educational system. Such practices could help to investigate hidden systemic structures that influence students' thriving.

As learning is an unpredictable journey that results in unique outcomes varying among students, curricula that force students to obey by the semester-cycles and deadlines offer little room for a free learning experience to let learning emerge naturally. This critique holds as its premise that students are intrinsically curious and do not need to be oppressed to learn. In particular, we see tension in the restriction of time and space. Students' attention is fragmented into several classes, co-curriculars, clubs, etc. All of these commitments fragment the learner's attention, which complicates the process of understanding the whole or larger picture. As discussed in "Overcoming the receiving model", campus systems direct the attention to the class-room and study experience and provide an architecture of disengagement regarding other parts of life such as cooking, cleaning, or vacation. However, to cultivate a critical living practice for social justice and sustainable development, this living practice needs to be part of the educational upbringing. In its very nature, living is holistic. An educational framework should therefore show respect for the various facets of life and endorse learning in all of them.

We need a learning and discovery method that aligns with the nature of the system we are studying. An example of such a learning experience is the 10-month experience from which this thesis arose. We provide a summary of the experience below.

Olin at Woodland Harvest

Figure 3.5: Our community for the Fall 2020 semester. Newly arrived students from airplanes wore masks.

At Olin College, the disruption caused by the COVID-19 pandemic in 2020 created a moment of campus-wide reflection that initiated an effort to explore intentional communal living to collectively work on meaningful projects as engineers. My partner and I contacted an off-grid permaculture farm in North Carolina to gauge their interest in a semester-long immersion of Olin College students and Wellesley alumni at their farm. The two women and their son who ran the farm agreed to embark on a semester-long endeavour with 15 students: Olin at Woodland Harvest Mountain Farm. Several students came back the next semester to continue their experience at the farm. We started this experience with the vision to create an intentional, leaderless community to build several dwellings, learn about living in nature and permaculture practices, and improve the off-grid system with solar panels and a wind turbine. The experience was deeply inspiring, challenging, hope-giving, and empowering. We see this experience as an example for a practice or discovery method to be immersed in a holistic learning process. Many insights from this experience are captured in a more abstract form in this paper.

It especially inspired us to rethink the framework for engineering work. We were partially designing for ourselves and for the farm owners, which changed our relationship as engineers to the project. We temporarily call this form of practice *relational immersion engineering* as it shifted our attention from a customer and problem analysis to a deeper synthesis of the field of intervention that was mainly informed by the strong relationship to the space and people. This perception relates to Ackoff's commentary (1963) on operational research. He states that in the phase of knowledge production for a project, we should put an emphasis on science as an activity [40] . What he calls systems science is a process of learning that "takes the systems as it finds them, in all their multidisciplinary glory" [41] . In this sense, we immersed ourselves in a field of opportunities to understand it in its wholeness to then contribute on several meaningful levels.

[40]: Ackoff (1963), 'General system theory and systems research: contrasting conceptions of systems science';

[41]: Strijbos (2010), 'Chapter 31, Systems Thinking';

To give the reader an idea of the field of learning opportunities and holistic nature of the experience, we decided to provide a list of meaningful points of learning. This list might seem long but is only a short glimpse into our larger experience.

This experience would not have been feasible without an overwhelming amount of financial support from our friends, college community, and many others. We sent out bi-weekly newsletters to keep our supporters up to date. Our website holds all of these newsletters, additional images, and detailed student experiences: OlinAtWoodlandHarvest.com

- The experience was a full immersion into something unknown. Most students had never lived off-the-grid, close to nature, or in an intentional community. As mentioned later in the section "Theory U" , this intentional immersion initiated a deep reflection process in many of us. Some of the topics of reflection were privilege, meaning of our major to ourselves, and living up to our values.
- It was a holistic experience in the sense that we students had to fully take of ourselves and our community. In many ways, students had to fully become their own housekeepers or mothers. This was the first time many of us have ever had to do the nitty gritty for ourselves and others. We cooked for each other, cleaned the house, built dwellings, improved the solar system, helped in the garden, took care of the animals, and many other tasks.
- Many students were living outside of their comfort zone every day. Olin's student population is largely white and upper-middle class, and the physical luxuries that are indispensable to this demographic were lacking at the farm. There were no high water pressure hot showers, laundry machines, dishwashers, and certainly no cleaning staff to pick up everyone's microtrash and scrub the toilet. Each student made personal assessments on which comforts they could forgo, and many realized they could survive without the modern luxuries or sterileness that our capitalist society convinces us of needing.

Figure 3.6: Our largest building was octagonally shaped. Building the roof was exeptionally challenging.

- Students were introduced to intense physical labor and close engagement with one's body, which are not typically practiced by a non-farmer. We were forced to experience and think about the labor that is usually done by others. This was another instance of discomfort, as farm work involved getting splinters, accidents with tools, and incredible strain on the whole body.
- Along with physical work came physical changes to the body that were new to some who were used to a sedentary student lifestyle, spent mostly looking at a screen and hunched over a desk. A long day of full body engagement meant we were hungrier, thirstier, and needed more sleep. We learned to practice interoception, or the awareness of what's happening inside ourselves. Some students began with skipping lunch, but after a few days of nausea and weakness, almost all realized that lunch was essential for a physical lifestyle.
- Around a third of the group had external school commitments, which were more or less fulfilled over a slow satellite internet connection. It became apparent that a holistic, well-rounded living practice was not reconcilable even with remote school commitments, which required a strong shift in the students' attention. We saw a clear clash occurring between the institution, which was part of the system, and the farm, which was trying to reject the system. This manifested itself in issues related to classism, authoritarian communication, and unhealthy productivity expectations from the institution's end.

Figure 3.7: We dug and tamped all 3 ft deep post holes for the buildings without power tools.

- Since the farm was a dynamic and chaotic environment compared to Olin campus, there was a sense of overwhelming amounts of tasks and projects to be done. Without enough self-will and internal motivation, it was difficult for students to overcome the hump of committing to a project and following through with it. Some became paralyzed from the overwhelmingness of the space and lack of direct instruction.
- The domestic chores unveiled gendered habits around cleanliness and willingness to participate in the kitchen process. As the two farm owners were two queer women who had to fight for their rights in many ways, the femininity-embracing culture at the farm created a strong contrast to the male-dominated engineering world. This shift from patriarchy to what we will call "attempted gender equality" exposed habits and mental models which lead to a reflection process in many of us.
- Unconsciously generated models of authority and social hierarchy began to develop in the group. There were no verbally assigned leaders and those who were inclined to fill those roles began to do so naturally. As we were all socially conditioned to live in a state of competition (whether that be a comparison of monetary wealth, moral standards, social capital, level of oppression, etc), complex relationships emerged as the group tried to find a power equilibrium. Of course, we could write an entire new thesis on the group dynamics.
- Three different generations got to know each other and lived together, including the farm owners, the students, and their younger son. During the second semester, a professor and administration staff visited us at the farm. It was a liberating experience to live

and create with people outside of our age group who usually teach classes or hold positions of authority.

- As an intentional community, we attempted to gather for group meetings once a week. The meeting was facilitated by the farm owners but no authoritarian rules or structures were imposed on the students besides fundamental safety guidelines. Most group meetings started with a grounding and a check-in. We noticed that communication beyond in-class group work required a lot of courage and reflection.
- We went on several group outings including kayak trips, backpacking, and star-gazing camping. Two of our community members who became friends at the farm decided to hike the 2,200 miles-long Appalachian trail together after several positive hiking experiences.
- Living off-the-grid meant that our delicious water came from a spring on the property. We heated the house with wood in the winter and used composting toilets. We reflected on our electricity consumption as our solar system and battery capacity was limited.
- For autumn equinox and other celestial events, we held ceremonies and welcomed the next part of the yearly cycle. This spiritual element invited a very intentional appreciation for the land that we lived on and what we receive from the natural world, and also encouraged us to be introspective and get in tune with our bodies and minds.
- We further learned to value and understand the surrounding ecosystem of which we were a part of. We walked on set paths to preserve the fragile native flora and used the rabbits' excretions as fertilizer for plants. Our two large guard dogs would bark at night but kept predators away, protecting our chickens and ducks. In the warmer months, our chickens blessed us with up to seven eggs per day.
- Many of us expressed our artistic explorations in forms of baking, drawing, painting, and singing. We had several dance parties and decorated our living spaces with lights and painted flowers.
- We self-organized around building three dwellings and a tree house, soon realized that we would not finish them before the beginning of winter. We engaged in daily teamwork, ranging from planning and designing the buildings to cutting the lumber and learning how to put on roofing.
- We dealt with conflict and tensions that arose over time, which became quite challenging. Some were resolved and others led to students choosing to leave early.
- Many of us tuned into more natural sleep cycles because our buildings were illuminated in dimmer light and great portions of our days were spent outside. Physically strenuous work throughout the day meant people would be tired and ready to sleep before 10pm, and the roosters and sunrise got people up early.
- To accommodate our group's electricity usage, we installed a 1000 W array of solar panels, built a pan-tilt mechanism for the solar mount, and semi-successfully maintained the already existent 80 W micro-hydro turbine. We further attempted to build a wind turbine. As part of a sustainable design initiative, we set up a glowing crystal light in the living room that indicated our battery status. For many of us, it was the first time to not be surrounded by high capacity

Figure 3.8: Group meeting to ideate building designs.

Our wiki holds info on most large engineering projects on the farm. Below you can find a link to our pan-tilt mechanism for five solar panels: wiki.OlinAtWoodlandHarvest.com first-world technological infrastructure. This setting allowed us to design engineering systems that created a direct impact in our and other peoples' lives. We documented our work on our own wiki to enable future visitors to work with and improve systems on the farm.

- We further became familiar with the cycles of life and death. A goat passed away of old age, we harvested our turkeys and roosters, and ate freshly hunted deer. The entire butchering process was also done on site within a few days of harvesting.

3.4 Practices for coexistence and co-creation

Not neglecting the change we can create as individuals, we exist around other humans that want to create a world for thriving existence. The complexity of our world makes it challenging to understand how to create conditions that favor our visions. However, we need our fellow humans to co-sense and co-shape emerging future opportunities. To explore and sense emerging future possibilities we have to engage with each other in some form. This section touches on a few practices and tools to facilitate this co-creative learning process. I believe there is still a lot of work to be done to learn how to live with each other and collaboratively explore the future in a non-hierarchical way. Creating change is inherently a collaborative process that requires an ability to listen to each other, engage in generative dialogue, cultivate our social fields, build collective intention, and eventually explore the future together [15] .

[15]: Scharmer (2018), *The Essentials of Theory U: Core Principles and Applications*;

Theory U

The Theory U is a method written by Otto Scharmer for change-makers. It acknowledges the unpredictable nature of any discovery process, the importance of social fields, and the presence of an internalized systemic model. His core ideas are very much aligned with our previous insights around a holistic science and give guidance for sensing future opportunities.

Sensing future opportunities requires us to connect with our inner source and tap into a deeper, shared and interconnected level of our humanity. If we want to facilitate a change from an old system, it is not enough to fight the old system. We need to tune into and become aware of the future that wants to emerge by shifting the inner place from which we operate. It is a search for our inner blind spot described in the section on spirituality.

He describes this shift as a transformation from an ego-system awareness to an eco-system awareness. While someone with an ego-system awareness mainly cares about their own wellbeing, someone with an eco-system awareness is driven by concerns that are informed by the well-being of the whole. "Pioneering the principles and personal practices that help us to perform this shift may well be one of the most important undertakings of our time" [13] .

[13]: Scharmer et al. (2015), 'Theory U: From Ego-system to Eco-system Economies';

To transform the pattern that keep us collectively stuck in past thinking and structures, an inner shift is necessary. As I mentioned in the section

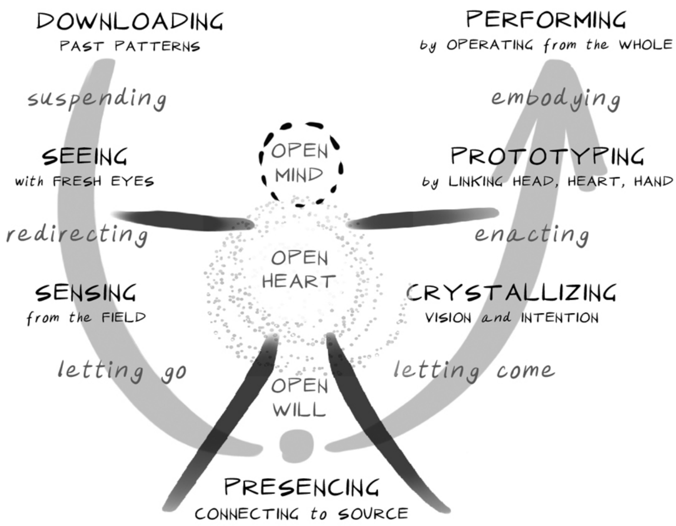

Figure 3.9: Theory U: The process of sensing and letting come the emerging future.

on adaptive cycles, most change is triggered by disruptions. Due to the extreme changes in our world, we are less and less able to rely on traditions and wisdom from the past to successfully shape our future. Our modern day's high-frequency lives and all the disruptions that come along with it require us to constantly reinvent ourselves. The Theory U, named after its U shape, describes the journey through a process of suspending our own judgment, redirecting our attention, letting go of the past, leaning into the future that wants to emerge through us, and letting it come. All of these steps can be found in the U-shaped illustration [13] . Leaning into the future is oftentimes an immersion into the unknown that gives us a wider perspective.

[13]: Scharmer et al. (2015), 'Theory U: From Ego-system to Eco-system Economies';

Some practices to facilitate a shift from an ego-system awareness to an eco-system awareness or holistic awareness are personal, others concern networks of people. On a personal level, one can cultivate an open heart, mind, and will through practices of mindfulness. The suspension of judgment is crucial to notice that there is a world beyond our patterns of past habits and thoughts [15] .

[15]: Scharmer (2018), *The Essentials of Theory U: Core Principles and Applications*;

In the end, however, we create change with other people. Therefore, practices and skills that concern our fellow human beings are of our great use. One of them is the ability to participate in listening to each other and generative dialogue. Dialogue is a quality of a conversation to see the system's patterns and assumptions collectively. Dialogue allows the system to see and sense itself [15]. For many, such practices would fall under the collective practice of spirituality to discover and cultivate what connects us.

The Theory-U suggests that we should intentionally immerse ourselves in places of most potential. Immersion will set us up for a path through the center of the U to let come of something unknown that wants to emerge. Furthermore, the social fields we explore and the connections we form will increase future opportunities. Intention strengthens our sources of self and gives us hold in a world that discourages alternative paths.

Once the emerging future starts to crystalize, we can explore the future by doing and creating with others. We can explore by the means of experiments to guide us further and create containers. Containers are holding spaces that elicit generative social fields by creating conditions conducive to collective thriving [15].

Collaborative groups

Many crises of our time are global challenges and therefore depend on global intergroup cooperation [42] . However, unbalanced communication flows hinder the system to see itself and engage in constructive conversation. We therefore see a need to cultivate our ability to have generative dialogue between people to discover our hidden mental models and prejudice. Prejudice-reducing effects proved to be stronger under "optimal conditions" such as cooperation, equal status within the situation, common goals, and support from authorities [43] . Therefore, collective action organized around collaborative groups is a meaningful form of facing our global challenges. Communication in co-creative, leaderless groups, however, distinguishes itself from communication in hierarchies in its complexity [44] .

[42]: Römpke et al. (2019), 'Get together, feel together, act together: International personal contact increases identification with humanity and global collective action';

[43]: Allport (1954), 'The Nature of Prejudice';

[44]: Starhawk (2011), *The Empowerment Manual: A Guide for Collaborative Groups*;

Change requires collective action and especially collective synthesis of the present moment. Oftentimes, social innovation starts on an individual level as what Westley and Antadze refer to as social entrepreneurship [45] . If successful and well received by their environment, the innovative momentum will be picked up on an interpersonal, organizational, interorganizational, and finally on the systems level. On the systemic level, we can refer to social innovation as a disruptive and catalytic effect that challenges the social system and its institutions by changing the distribution of power and resources [45].

[45]: Westley et al. (2010), 'Making a difference: Strategies for scaling social innovation for greater impact';

On an organizational or interpersonal stage, potential forms of a social enterprises are intentional communities or shared housing complexes that are united through a shared vision and actions surrounding it. Collaborative groups can be extremely empowering to their environment and members and can eventually bring forth larger systemic change. By collaborative groups I refer to groups that are created around shared power and the inherent value of every member. However, only around one out of ten new collaborative groups can sustain themselves over time no matter how big their vision and collective inspiration [46] . Also, most hippie communities of the 1960s failed [44] .

[46]: Christian (2003), *Creating a Life Together: Practical Tools to Grow Ecovillages and Intentional Communities*;

[44]: Starhawk (2011), *The Empowerment Manual: A Guide for Collaborative Groups*;

Ideally, collaborative groups are structured to encourage cooperation, efficacy, and friendship [44]. However, the reality is that self-governed, leaderless groups can spiral up in conflict and run against walls as people are socialized into hidden colonial models of social dynamics and authority. While management of hierarchies is a well-explored topic, governance through authentic collaboration is a rarified practice in Western cultures. Communication and generative dialogue are therefore abilities that we need to foster collectively to build the skills of authentic collaboration. The communal-living experience with my college and Woodland Harvest Mountain Farm gave me the profound realization: How do we dare to want to create solutions to the major issues of humanity (as engineers) if co-existence and co-creation with fourteen other people in a household is so incredibly hard? I believe that we have a great deal to learn about existing and talking with each other to engage in a free and fair co-creative process.

Generative communication

The Empowerment Manual by Starhawk (2011) attempts to guide through a variety of practices, meditations, and stories to enable collaborative groups to thrive [44] . She has been working and living in collaborative groups ranging from activist groups to living communities for more than 50 years of her life. Examples of practices from her book are intentional group meetings, collective mindfulness exercises, or collective vision building. Starhawk recommends that groups that embark on a journey together engage in a vision building process, explore their core values, clarify their intentions and goals, and settle on governance agreements to have a uniting picture in their minds of what they want. However, big visions raise the group's risks of a perception of failure. As our values inform our vision, group exercises that explore every member's values are helpful to relate to each other over a set of core values. If values are explored together, others can accept or challenge perspectives that would stay otherwise unseen [44].

[44]: Starhawk (2011), *The Empowerment Manual: A Guide for Collaborative Groups*;

Most of us from the Western world were raised in hierarchies. In hierarchies, she argues, there is generally one proper path for communication, up the ladder or down the ladder. Collaborative group structures, however, are far more complex. It is often not clear who should make a decision, who needs to be included in the process, and who is left out. Friend groups come up with ideas and plans independently and might not consult other affected parts of the group, often unintentionally. Continued patterns of ineffective communication generate conflict and reduce trust among the community members [44].

When people come together united through a shared vision, they bring their unexamined norms to the circle. Some people are quiet and tend to downplay problems, others are unaware of their habits to interrupt due to their privileged past. Starhawk recommends reconciling our different styles of communication by examining our norms. We can ask ourselves "What style of communication did your family of origin use?" or "How might we respond to people who might have different norms?"

Certain unconscious or conscious norms, in particular, reinforce power structures and privilege no matter if the group calls itself leaderless. There is evidence that especially international personal contact reduces prejudice and privilege reinforcing patterns against group members from different backgrounds and increases identification with humanity and global collective action [42] . Among others, patterns that reinforce privilege are interrupting others, taking ownership over other people's accomplishments, or taking the center stage. Such patterns can suppress other voices and reduce participation [44]. Participation, however, is key in collaborative groups. Group members need to feel seen and respected. Among others, ways to alleviate the impact of privilege and social power are to give quieter people space to talk, ask people to clarify themselves in times of confusion, offer up your skills and knowledge to others, and put a strong emphasis on other people's contributions [44].

[42]: Römpke et al. (2019), 'Get together, feel together, act together: International personal contact increases identification with humanity and global collective action';

As with every complex undertaking, these ideas are only a small part of creating the conditions for a thriving community. There are endless forms in which communities can thrive. Smoothly running collaboration requires cyclic reflection, courage, and a strong will to work toward an empowering, co-creative process.

3.5 Spirituality, getting to know our mind, body, spirit

A holistic science is commensurate with life. It therefore pays attention to all aspects of life, including personal consciousness and spirituality. From the point of view of Holism, spirituality and science are not a contradiction. Spirituality forms our values, encompasses the mysteries of the cosmos, brings us closer to being a better human being, and shows us how to spread love and respect for other living beings. A science without a soul would clearly lead to a disaster [18] . I believe that spiritual wisdom, inward and outward, is essential in leading to the awareness of being interconnected with all of nature. Systems thinking is not only a synthesis of external relationships and information flows. Engineers, creatives, leaders, or managers are change makers that exist in the systems in which they operate. The quality of the results in any social system depends on the consciousness from which the people in that system operate [13] . Holistic thinking is always a dialogue with yourself, which requires that the individual switches from seeing the system as something external to seeing the system from an angle that includes one's own self . It is a form of inner consciousness that needs to be practiced and explored, and we can refer to this capacity as 'mindfulness'. Mindfulness is the capacity to experience the present moment and simultaneously pay attention to your attention [15] . Otto Scharmer calls this process 'presencing'. It is a combination of the words present and sensing, sensing the present. In the process of presencing, one turns inward toward the source of one's mental process rather than focusing on the object of attention.

[18]: Capra (2016), *The Systems View of Life*;

[13]: Scharmer et al. (2015), 'Theory U: From Ego-system to Eco-system Economies';

[15]: Scharmer (2018), *The Essentials of Theory U: Core Principles and Applications*;

With the displacement of religion in educational institutions particularly in the West, spiritual wisdom has not had a dominant place in higher-ed curricula. A science without spiritual wisdom can lead and has led to disastrous results around the globe. A holistic science, on the contrary, would allow for a container or environment that holds space and time for the following points, rounding up our experience as learning beings. This is not to say that engineering should necessarily have its own spiritual tradition. The following points are rather meant as inspirations to let emerge spirituality, including already existing wisdom traditions. This list, as all texts around holism, is by no means complete and an invasion for further inquiry.

Slowing down — It takes time to sense what is going on inside ourselves (body, mind, spirit) and around us. If we want to let go of past assumptions and thoughts about the nature of reality, we cannot rely on our fast thoughts and downloaded content. It is helpful to remind ourselves that sensing our body takes longer than having a thought due to the longer neurological pathways. Therefore, we need to slow down, feel, and listen to the signals from our body.

Understanding your opening process — Part of understanding yourself is to understand your opening process. How can I confront myself with my blind spots? Oftentimes, we do not have an awareness of how our individual attention and awareness shape the social reality around us. Even though we know what we want to do and how we want to do it, we are far less aware of our inner place from which we operate. The engagement with our inner blind spot is a learning journey of understanding ourselves as part of the system that we like to perceive as something external; it is facilitated by participating in community. Through a shared inquiry, one gives and receives reflective insights These reflections, like the reflection in a mirror, are 'outside' our field of view. Participating in an active inquiry, one is liberated, allowing us to understand the deep source inside of us, from which we operate and consciously make alternative choices rather than being beholden to habitual behaviors [13] .

[13]: Scharmer et al. (2015), 'Theory U: From Ego-system to Eco-system Economies';

Interoception — Interoception is our ability to perceive sensations from inside our body, our system. Life is a constant learning process about our needs. While it seems important to be conducive to other life, it is mutually important to be conducive to ourselves. If we believe that we should resemble our own autopoietic system, we cannot lean back and wait for someone else to take care of us. We need to be concerned with maintaining ourselves to create conditions for ourselves that allow us to thrive and be healthy. Listening to our inner sensations and their meaning for ourselves is an intentional process that requires time and space. A familiarity with our needs can strengthen our will to be proactive about change that will be good for us.

Cultivating our will — We are born into many systems that tell us what to do. However, it takes far more discipline or will to follow through with tasks of life that are not imposed on us. For instance, we can be forced to wash the dishes or work on our inner will to contribute to a tidy place. A daily routine, for instance, is one way to strengthen our will. By *will* we are not referring to our inner voice that forces us to do tasks we do not seek out. It is rather deeper, intrinsic drive that arises from an awareness of ourselves and the world around us.

3.6 Reductionist wisdom and analysis

In many parts of our lives, it is absolutely appropriate to learn from the past and apply reductionist concepts. Traditional engineering wisdom around non-living, uncomplex systems is an essential part of an engineer's repartour. Especially for a holistic engineering education, it is crucial that engineers are familiar with the traditional knowledge and the mental models beneath this knowledge that have shaped the field for the last few decades. However, it is critical that one understands when this scientific approach is fit for the purpose at hand. Detailed subsets of knowledge serve as technical manuals for engineering work ranging from analysis to design and manufacturing. It is not my intention to suggest that engineering students should be familiar with every small concept in every subfield. Engineering education should much rather introduce students to threshold sets of knowledge that empower them to teach themselves when they know that they don't know.

For instance, if we seek to build a tiny cabin, we have to be able to calculate the stresses in the building. Numerical calculations will inform the design decisions to prevent an unsafe construction. The screws used for construction were rigorously tested. Their materials were tested for their strength, corrosion resistance etc. A detailed analysis of all the components and tools conducted by past generations of builders and engineers makes modern construction possible. Manuals and guidelines help to facilitate safe and effective work. And before we start to buy all the materials, we want to be able to predict if the structure will hold up during a dance party. If we want to create a door knob on a lathe, we need to know about the properties of stainless steel. In this sense, traditional engineering knowledge derived from the reductionist sciences is irreplaceable when we work with simple, non-living systems.

We clearly need a lens on our physical world that breaks it into smaller pieces to understand and predict their behavior when such a lens is fit for the purpose: working with non-living matter. Depending on the field of engineering, a great amount of technical knowledge is necessary to comfortably make decisions. For a holistic engineering education, the critical thresholds of reductionist concepts and understanding should be identified along with the situations where they apply. As an example, the following domains of understanding might represent the threshold for technical knowledge:

- The first and second laws of thermodynamics and their implications
- Newton's laws of linear and rotational motion applied to simple rigid bodies
- Elementary chemical reactions near equilibrium conditions
- Basic electrostatic and electrodynamic concepts and relationships
- Basic static and dynamic concepts and relationships
- One-dimensional flow of charge and thermal energy (steady and transient)

It seems to be worth noting that even systems governed by the simple laws of linear and rotational motion can exhibit quite complex behavior. A pendulum on the borderline between rotation and vibration, for instance, can show a variety of motions, including random turbulent-like excursions. And in the world of chemistry, assumingly steady equilibrium reactions display complex self-organizing behavior, which manifests itself in spatial structures or propagating wave forms. These two examples suggest that the margin between "simple" and "complex", "order" and "disorder", is more narrow than we might think [2] .

[2]: Prigogine and Nicolis (1985), 'Self-organization in Nonequilibrium Systems: Towards a Dynamics of Complexity';

By no means are we attempting to dismiss the complexity and usefulness of the reductionist sciences. However, at some point, we will have to consider the tiny cabin's relationship to its surroundings, the larger systems. At that point, we will be lost basing our assumptions on the smallest parts of the system.

4 Conclusion

If we want to create a world of social justice and sustainable development, engineering education needs to redefine its relationship with this planet and learn from living systems. It therefore needs to be built on a set of mental models and assumptions that reflect the dynamic complexity and interconnectedness on our planet.

We need a science that is commensurate with reality. Such a science is loosely organized around life phenomena, dynamically complex systems thinking, inward and outward spirituality, the reductionist sciences, and learning practices for co-creation and research inquiry. A holistic science is naturally close to the nature of being alive on this plane. At its very core, we ask the question: What does it mean to be alive as an engineer in the 21st century? We propose an approach that puts us in the position of nature's apprentice to mimic how nature creates conditions for thriving beings. It is not an innovation and rediscovery at the same time and reveals that past schools of thought used to approach the study of nature in an organic, holistic manner. Such a holistic science would include all aspects of life including the household, family, and breaks. It further has to hold space for the spiritual aspects of life to form our values and direct our actions as technologists.

A holistic engineering education would arise from a holistic ontology and consequently be its own holistic autopoietic system - a recreation of a holistic science. As nature creates conditions for thriving, we hope that a science inspired by the properties of nature will inform engineering efforts that create similar conditions.

The mentioned aspects of a holistic science serve frameworks and models but will never fully describe all aspects of our world. It is the very beauty of a holistic science that with a few basic concepts in mind, one can embark on an empowering journey of discovering and understanding our world. This journey is defined by cycles of reinvention of ourselves on a personal and collective level to co-create future changes. We have yet to cultivate practices and principles collaboratively to shape our future but believe that an understanding of our reality as whole will be conducive to informed (engineering) work to create a thriving existence for every living being on this planet.

Appendix

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