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Mycorrhiza Framework: towards an Engineering Education framework for Social and Environmental Justice

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Towards the Mycorrhiza Framework: An Engineering Education framework for Social and Environmental Justice

Abstract

Nature and people require a drastic change in how we educate engineers. Social and Environmental Justice should be a fundamental pillar in engineering education. Both the complexity of our current problems and the social and environmental injustice that most people endure demand engineering to go beyond the technical problems, question the impact of our engineering solutions, and incorporate other ways of doing and being in engineering. Engaging in engineering, and engineering education without awareness of other beings and the Ecosystem, leads to immense harm, especially to underrepresented people and their ecosystems. In this article, I present my first thoughts on an engineering education framework that hopefully will guide educators and students through the relationships and interconnections between three levels: individual, people, and the Ecosystem. To illustrate these interconnections, I use the biological concept of mycorrhiza as a simile of these invisible connections. Mycorrhiza is a symbiotic association between fungi and plants that cycles nutrients to improve the whole ecosystem. The Mycorrhiza framework aims to raise awareness of the effects of engineering education and work, incorporate social and environmental justice in engineering education, and move closer to helping people freely and fully develop in a sustainable world.

I. Introduction

It is essential for people and the Ecosystem that we raise awareness of our engineering impact. Demanding for people to take action, Singer [1] presented an ethical decision where we would see a child drowning. Most people would do their best to come up with a solution to help the child. Engineering with visible results or direct implications seems to make it easy to care for the people or beings impacted; it becomes easier to make an ethical decision when the direct effects are evident. Now imagine an engineer working in construction in New York between 1920 and 1970, who is requested to make bridges with a height restriction that would not allow buses to go under them. This engineering decision marginalized even further the poor and black communities of New York, who normally used public buses for transportation [2]. This example is an indirect implication of engineering work, and some people would do it even if they did not intend to marginalize underrepresented people. Finally, imagine an engineer working for several years to find the most efficient way to produce clean energy, they might be interested in our relationship with people and the Ecosystem, and at the same time, they might not be aware of the impact of extracting lithium from sacred land, leaving thousands of people without water and an ecosystem on the verge of collapsing [3,4]. Creating an engineering solution to improve the use of clean energy with a material whose extraction has negative implications on people and the Ecosystem, has a more complicated (invisible) effect, and therefore a more complicated ethical decision. As problems become more complex, it becomes more

challenging to be aware and care about those people and ecosystems who we might unintentionally and invisibly hurt with our engineering decisions.

Beings and ecosystems are connected, our acts impact others, and we don't usually see further than a few degrees of separation. Within those effects, engineering has major implications for people and the Ecosystem. If engineers were to raise awareness of those implications, engineering has the potential to greatly improve the lives of people and other beings in the world. The purpose of the Mycorrhiza framework is to raise awareness of the effects of engineering work on people and other beings who shape our Ecosystem. This article starts with a brief and open understanding of engineering, then the explanation of the Mycorrhiza framework, followed by the three levels of the Mycorrhiza framework application, continued by discussion, conclusion, and my positionality.

II. Engineering education background

Engineering is indeterminate and we have not yet defined what it means to be an engineer. Pawley [4] found three universal narratives of engineering in engineering faculty: engineering as applied science and math, engineering as problem-solving, and engineering as making things. Figueiredo [5] argues the need to use four dimensions in engineering epistemology: social and basic sciences, design, and practice. Purzer et. al., [6] use negotiating risks and benefits as the center of engineering optimization, engineering analysis, user-centered design, design-build-test, engineering science, and reverse engineering. I argue that engineering and engineering education could greatly benefit by being aware, appreciating, and respecting the relationships with each of the proposed levels of the Mycorrhiza framework: Individual, People, and the Ecosystem. The fact that hundreds of millions of people are suffering from hunger, poverty, and lack of health care, education, water, safety, and shelter, is a clear reason that we need to change the way we are doing and being engineers. Martin and colleagues [7] claimed that effecting change in the status quo of engineering education and research requires adopting a critical and self-reflective approach that encompasses socioeconomic and cultural contexts, geographical differences, prevalent biases, and cognitive assumptions. Engineering education needs to look inside and change the way we are doing and being. To decolonize engineering education, Cicek et al., [8] proposed inward-facing strategies within engineering education and incorporating Indigenous/local knowledge systems and practices. As Paulo Freire would say in Pedagogy of the Oppressed [9], every revolution is pedagogical in nature, therefore this Mycorrhiza framework starts with engineering education as a beacon of transformation.

III. Mycorrhiza framework

Mycorrhiza is a symbiotic underground (invisible) interconnectedness between fungi and plants, which cyclically share nutrients for the benefit of the Ecosystem. Multiple cultures in the Amazon, such as the Bora, Pira-Tapuya, and Yagua, believe that through invisible connections, trees that are sick are fed by this network (Mycorrhiza) until they get better.

What is fascinating, is that because of what they see in the Ecosystem, these Amazonian indigenous tribes (and other tribes and peoples) behave differently from Western societies. For example, without any concept of insurance, they help each other when a catastrophe happens to one of them; they feed the sick tree until is better, so the Ecosystem can thrive. A Mycorrhiza connects freely in any direction and without hierarchical understanding; it is a-centered, it is not top-down; it is egalitarian in nature; it helps us understand our intricate and holistic connections to other beings.

The Mycorrhiza framework is inspired by the Holographic Epistemology by Meyer [10]. This indigenous epistemology considers an inclusive lens of the three aspects of nature: physical, mental, and spiritual. The Mycorrhiza framework pulls from Meyer the epistemology of body-mind-spirit as a simultaneous event where balance is necessary for the individual, people, and the Ecosystem to thrive. Perceiving the connections (Mycorrhiza) is not enough "It has always been about reverence, the act of care for others and for our earth" [10]. We care for those who are close to us; the more aware we are of others, the closer we are, the more we care.

Baruch Spinoza based his philosophy on ideas of relationships or interconnections, processes, and the change of power ("affect") these interconnections have on others [11]. Spinoza believed that every essence (individual) is part of an interconnected (Mycorrhiza) and infinite substance (Ecosystem). Spinoza's work inspired Deleuze and Guattari's [12] concept of Rhizome, which in biology is a mass of roots that sends out shoots from its multiple nodes; think of ginger or turmeric. Deleuze and Guattari used the biological concept of Rhizome to represent the complex connections between individuals and systems, individuals with other individuals, and systems with other systems; a sociological representation. Mycorrhiza shares most of Deleuze and Guattari's [12] Rhizome's principles[1]. Mycorrhiza mainly differs from the Rhizome in that (a) the Mycorrhiza could be predicted (imagine being able to predict what a new node or connection would do to the part of the network) and (b) its connections with other beings and nature are as important as the connections between humans, i.e., the Mycorrhiza is not human-centered. The philosophical difference[2] between Rhizome and Mycorrhiza is the conception of universal truths. I believe there are universal truths. If there are universal truths, then an engineer can eventually understand, feel, or be aware of the future, or at least some of the future, implications, and invisible connections of their solutions. In fact, the Mycorrhiza framework encourages engineers to use this lens to be aware of the potential effects of our engineering solutions on ourselves, other people, and the Ecosystem.

[1] The six principles of the Rhizome are: connection, heterogeneity, multiplicity, asignifying rupture, cartography, and decalcomania (Deleuze and Guattari, 1987)

[2] The specific difference between the Rhizome and the Mycorrhiza are in Rhizome's principle 3 multiplicity, and principle 5 cartography.

Figure 1. Mycorrhiza's principles

In conclusion, Mycorrhiza is a biological example to represent the complex interconnections between beings (humans, animals, plants, fungi, rivers, rocks, …) and the Ecosystem. The Mycorrhiza framework uses 7 principles (Figure 1) to describe the characteristics of these interconnections in our inescapable relation to our humanity, people, and the Ecosystem. The purpose of the Mycorrhiza framework is to provide engineering educators with a lens[3] of social and environmental justice.

IV. The three levels of application of the Mycorrhiza framework: Mycorrhiza Praxis.

The need to use the Mycorrhiza framework arises from the pressing social and environmental challenges we continue to confront. At the individual level, having a meaningful life requires a sense of meaning, interpersonal relationships, the pursuit of personal goals, and a deep connection to self and others [13]. Klussman and her colleagues argue that the awareness of oneself is related to the awareness of one's sensations, thoughts,

[3] An Axiological, Ontological, Epistemological, and methodological lens.

and emotions. However, most people in the world, especially underrepresented people, don't have the luxury or the time to search for a meaningful life. Day to day, according to the United Nations' Agenda for Sustainable Development, by 2030, 575 million people will still be living in extreme poverty, and 600 million people will be expected to face hunger. Ruha Benjamin [14] denounces how technology and artificial calculators (aka. artificial intelligence) are not neutral tools but instead are codified with racial biases and hierarchies. She even uses the term "Jim Code" to define these new ways of racial oppression. Technology and engineering applications should not fall into the reinforcing of racism that Umoja Noble [15] and Ruha Benjamin [14] denounce.

At the Ecosystem level, one example that literally touches us all is the omnipresence of microplastics which are found in air, water, food, even inside humans, and most likely in all species; their health effects are still unknown [16]. Barnet and colleagues [17] found that people would change their perception and behavior to reduce instead of recycle when they were informed about the polluting impact. The more aware, the more we care. The more degrees of separation, the harder it is to take action, and sadly as it is, most people wouldn't consider something a problem until it directly affects them or someone or thing they care about. Unawareness of the immediate effect of our actions and our engineered solutions leads us to believe we are not affecting other beings, so we continue optimizing the income of companies and not the well-being of people and the Ecosystem. We as engineers and engineer educators, need to take immediate action to deal with these complex and interconnected issues that are affecting us as individuals, as a species (people), and as a whole (Ecosystem).

a. Individual level

At the individual level, engineering learning-teaching under the Mycorrhiza framework concentrates on maintaining a harmonious balance between the cognition-emotion-spirituality triad. Cognition leads to reason which enables comprehensive ethical decisions [18], while emotions wield a direct influence on engineering ethics [19]. Haidt [20] contends that intuitions are fundamental in shaping moral judgments and ethical decisions. Moreover, Immordino-Yang and Damasio [21] found a neurological relationship between cognition and emotion, coining it "emotional thought". Within the realm of emotional thought, learning, memory, and both individual and social decision-making take place. Cognition and emotion thus stand as indispensable elements for learning-teaching. Recognizing and understanding cognition and emotion are essential for fostering self-connection and comprehending internal states and intuitions [13]. Meyer [10] elaborates on Spinoza's view of spirit as awareness, an awareness of reason and emotion; an awareness of the interconnections and impact ("affects") of external causes. In the context of the Mycorrhiza framework, awareness is a fundamental part of spirituality, awareness of the interconnections between all aspects of existence, including cognition and emotion, the individual with people, and the Ecosystem. Spirituality serves not as a religious

interpretation of an afterlife or the soul, but as an awareness of the connections with everything –Mycorrhiza.

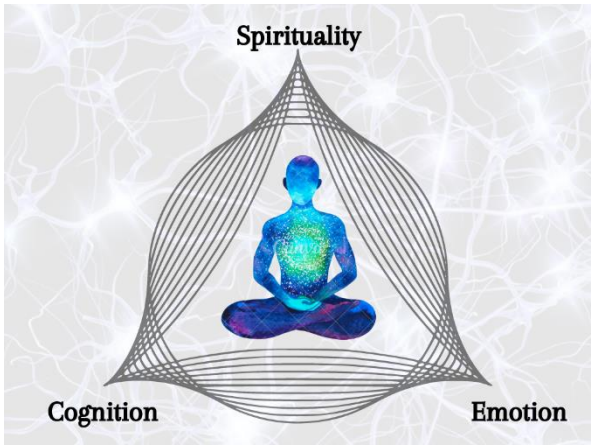

Figure 2. The individual triad

To care for others, we need to start caring for ourselves. As shown in Figure 2, keeping a balance of cognition-emotion-spirit or body-mind-soul is a good way to start. When doing engineering work or engineering education, engineering educators could ask students questions related to the Japanese concept of purpose, Ikigai[4]. These and other questions are offered in Table 1.

Table 1

Practical questions to ask engineering students at the Mycorrhiza's individual level

Questions at the Individual level	Mycorrhiza's principle
Is my engineering work connected to my purpose?	Connection; Heterogeneity: Awareness
How is my engineering work connected with what I care about?	Connection; Heterogeneity; Transferable: Awareness
How is my engineering work helping people and/or the Ecosystem?	Connection; Egalitarian; Adaptability; Awareness
Is my engineering work connected to global or local pressing issues? (e.g., United Nations' 17 goals)	Awareness; Egalitarian; Decentralized; Transferable
How do I feel about the engineering work that I'm doing?	Heterogeneity; Connection; Awareness
How do I perceive my engineering work in connection with my community and/or the Ecosystem?	Connection; Egalitarian; Awareness

[4] Ikigai is the Japanese concept of purpose as the intersection of four spaces: What do you care about? What are you good at? What does the Ecosystem need? And what does the Ecosystem value?

b. People level

Engineering work and engineering education under the Mycorrhiza lens focus on the well-being of people. Every day, hundreds of millions of individuals grapple with pressing difficulties such as poverty, hunger, gender inequality, inadequate access to healthcare, education, and water, poor living conditions, and the consequences of war and violence [22]. Johan Galtung [23] describes imperialism as a structural phenomenon rather than a product of an institution or an individual, a system that perpetuates inequality, and resists changing this inequality. Much like the Rhizome of Deleuze and Guattari [12], Galtung's [23] definition of structural imperialism shows the a-centered, multifaced complexity behind structural violence and inequality.

The complexity and urgency of Social Injustice require the work of engineers to help bring people to a society where everyone has equal opportunities, rights, and resources. The Mycorrhiza framework provides a lens that considers people as one of the three fundamental tenets of engineering education. Fila et al., [24] proposed a framework for considering people in engineering and engineering as work for society. Engineering for people as clients, providers, and people involved in the engineering process; with people as teams developing the engineering process; and as people. The authors present the idea of working collaboratively with diverse groups of people to address the needs of different participants in the engineering process.

Lucena [25], inspired by the philosopher Nussbaum, provides one of the multiple definitions for social justice.

> "Social justice practices, including those by engineers, should attempt to an equal distribution of rights, opportunities and resources in order to enhance human capabilities and reduce the risk and harms among the citizens of a society" (p.10)

Every engineering creation, and engineering education act, is a vote to guide society towards a certain place. Leydens and Lucena [26] argue Social Justice dimensions are inherent to engineering and are made invisible. They argue that engineering problem-solving is sociotechnical, because of the impact on society through technology. It is common to have engineering solutions that look to reduce costs and increase income to optimize the net profit of a company while neglecting the sociological impact. In some cases, (e.g., clean energy) we even see engineering and engineering education focus on an apparent laudable task (moving away from fossil fuels), but during the process, some not immediately connected people are affected. Lithium exploitation is affecting Atacameño's indigenous communities, in a very similar way that oil companies were and are still affecting indigenous people in South America and other regions of the world. This is a perfect example in which the Mycorrhiza framework could be helpful. We need to move away from fossil fuels, and clean energy shouldn't repeat the same injustices towards people and the environment that fossil fuels have done and continue doing. Engineering and engineering education must have the well-being of people as one of the tenets. Table 2 offers some of the questions the Mycorrhiza framework would encourage engineering educators to ask students.

Table 2.

Practical questions to ask engineering students at the Mycorrhiza's people level

Questions at the People level	Mycorrhiza's principle
How is this engineering solution impacting the people involved in the process?	Connection; Egalitarian
How can we involve the people impacted by this engineering problem?	Connection; Egalitarian; Heterogeneity; Decentralized
Who do we need to bring into the team to see what we might be missing?	Connection; Adaptability; Heterogeneity
Who is benefiting from this engineering solution?	Egalitarian; Transferable
How can we increase the engineering solution's benefit to more people? (i.e., create value)	Egalitarian; Transferable; Decentralized; Awareness
How is this engineering solution affecting people at the production, development, and end-of-production sites?	Egalitarian, Decentralized; Transferable; Awareness
What features can we design to mitigate the risk of affecting the social reality of people involved in the process of this engineering solution? (e.g., durability)	Connection; Adaptability; Decentralized; Awareness

c. Ecosystem level

Environmental justice is intrinsically related to social justice. Riley [27] argues that both have multiple definitions one environmental justice definition states the equal value of non-human species, humans, and biodiversity. Equal value means that people, beings, and non-traditional beings have the same rights. Human supremacy leads to exploitation without consideration of other beings beyond the ones in power, and I believe it encourages other types of supremacy among humans.

As stated by Cicek et al. [8], engineering education needs to look inward and incorporate indigenous knowledge to decolonialize engineering and therefore improve our relationship with the Ecosystem. Kennedy et al., [28] argue there is a need for a new philosophy in engineering education. Leigh et al., [29] and Ruta et al., [30] have presented different efforts to include Indigenous knowledge in the Engineering curriculum. Kennedy and colleagues [28] presented a Venn diagram model with three circles representing the intersection between Aboriginal perspective, Dominant perspective, and Engineering perspective. The authors argue that each perspective co-exists and the intersection is a place to help everyone. Everyone includes all beings, non-human and non-traditional beings such as mountains, minerals, and rivers. In 2017, *Te Awa Tupua* (River with Ancestral Power) Act established recognition of the Whanganui River from its origins high in the mountains to its mouth down in the ocean of New Zeland. The act recognizes the Whanganui River as indivisible and living whole, with all its physical and metaphysical properties [31]. Eduardo

Gudynas [32] has a central tenet of the movement *Buen Vivir* (good way of living) that the Ecosystem is a *Sujeto de Derechos* (person or entity with legal and moral rights), disrupting the traditional anthropocentric way of being and doing. *Buen Vivir* ideals have reached the Dominant perspective of Bolivia and Ecuador, these countries have included indigenous epistemology and ontology into their constitution, giving value not only to the different peoples that live in the Andes region but also giving rights to the Ecosystem thanks to the traditional relationships and connections between the indigenous communities and the Land.

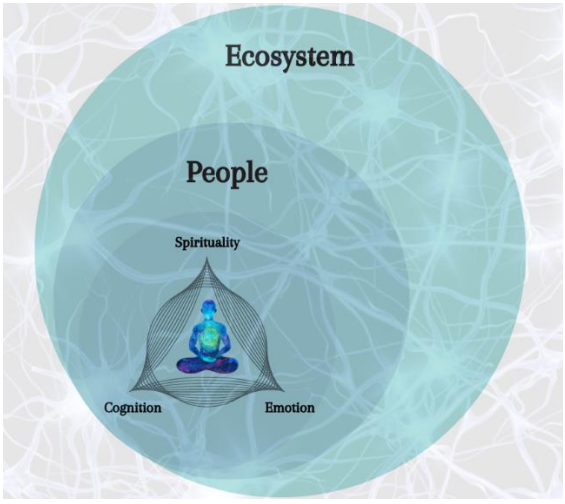

Figure 3. The individual is not in the center of the Ecosystem.

Figure 3 presents humans not in the center of the Ecosystem, as a node of a much larger, intricate, and heterogenous system. To challenge human supremacy and find a more sustainable and loving relationship with the Ecosystem, in Table 3 there are some of the questions the Mycorrhiza framework would encourage engineering educators to ask students:

Table 3

Practical questions to ask engineering students at the Mycorrhiza's Ecosystem level

Questions at the Ecosystem level	Mycorrhiza's principle
How can we create value for the Ecosystem while developing our engineering solution?	Connection; Egalitarian; Decentralized; Transferable; Awareness
e.g., Beyond the Paris Agreement and the negotiation of carbon credits, what can we truly give back to the Ecosystem we are taking so much from?	
What are the connections between this engineering solution and the Ecosystem?	Connection; Transferable; Adaptability; Awareness
How are we impacting the land where materials are being extracted, processed, and disposed of?	

What non-traditional beings are being affected by this engineering solution? e.g., What Ecosystems and animals are being impacted by having a highway in this place?	Connection; Egalitarian; Heterogeneity; Transferable; Awareness
Who can we involve that can help us be more aware of our impact on the Ecosystem? Is there a traditional land-care-taker or an expert who knows the interconnections of the Ecosystem we are impacting?	Connection; Egalitarian; Decentralized; Transferable; Awareness

V. Discussion

We as engineers, engineering educators, and engineering students, have the responsibility of solving engineering problems with a social and environmental justice lens. The complexity of the interconnected sociological and ecological systems requires engineering to be aware of the direct and indirect implications of our engineering work. The Mycorrhiza framework serves as a practical lens to raise awareness of the social and environmental impact of our work. Through each of the three levels, the Mycorrhiza framework invites us to ask ourselves what would lead to a more holistic engineering work, taking into account different actors and being aware of the complexity of the interconnected systems we live in.

Each level suggests questions related to finding purpose, balance, and both social and environmental justice in our engineering work. An engineer creating, working, and learning-teaching with a purpose connected to what they care about, what they are good at doing, what people and the Ecosystem value, and what people and the Ecosystem need, is more likely to have an awareness of the invisible interconnections, an awareness of both the direct and indirect implications of our engineering work. Table 4 presents a compilation of some questions for each level that would help an engineer and engineer educator be more aware of the indirect implications of our work.

Using the Mycorrhiza framework does require more time and more people to create something; requires engineering solutions that are durable, useful, and hopefully beautiful; requires engineering education to incentivize critical thinking for those invisible connections that affect others directly or indirectly; requires coherence of the engineer and the educator; requires to care; requires to find a purpose and to ask ourselves those questions that encourage social and environmental justice.

Table 4.

Printable table of questions

Level	Questions	What might improve in engineering students?
Individual	Is my engineering work connected to my purpose?	Intrinsic motivation
	How is my engineering work connected with what I care about?	Well-being, engagement, and creativity
	How is my engineering work helping people and/or the Ecosystem?	Commitment, resilience, and satisfaction
People	Who do we need to bring into the team to see what we might be missing?	Teamwork skills, sense of social justice, and caring.
	How is this engineering solution impacting the people involved in the process?	Awareness, responsibility, and ethical values
	What features can we design to mitigate the risk of affecting the social reality of people involved in the process of this engineering solution? (e.g., durability)	Ingenuity, sense of social justice, and creativity
Ecosystem	How can we create value for the Ecosystem while developing our engineering solution?	Awareness, ingenuity, and creativity
	What are the connections between this engineering solution and the Ecosystem?	Awareness, transferability, and caring.
	What non-traditional beings are being affected by this engineering solution?	Awareness, responsibility, and sense of sustainability

VI. Conclusion

To face the complexity behind inequalities in our society and the catastrophic damage we are doing to the Ecosystem, engineering, and engineering education must take rapid action for Social and Environmental justice. The purpose of the Mycorrhiza framework is to incorporate social and environmental justice in engineering learning-teaching. The Mycorrhiza framework should help instructors and students ask questions and consider a lens from each of the three levels: Individual, People, and Ecosystem. A more holistic way of doing and learning-teaching engineering can hopefully lead to more holistic solutions that will guide us towards an egalitarian society in a sustainable world.

VII. Positionality

Epistemologically, I believe that knowledge is shared, not transferred. This concept is conceived in Slavic languages as *Obuchenie* which translates into simultaneously learning and teaching. Furthermore, I believe in universal truths, and at the same time, I believe that each of us has a subjective perspective of those universal truths. We should incorporate more inductive and deductive angles to our knowledge construction or acquisition; however, I think that while we conceive, think, and behave as separate beings, we won't be able to be subjective. **Methodologically**, beyond the scientific method, I value other ways of knowing and being. Within the scientific method, I see mixed methods as a way of doing

research more comprehensively. Due to the subjectivity mentioned before and the brutal socio-economic disequilibrium, I agree with the importance of recognizing the researchers' positionality. Because I disagree with the end justifying the means, I believe that the purpose and core philosophical principles of the researchers should guide every step of the research process.

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