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Empathic Design in Engineering Education and Practice: An Approach for Achieving Inclusive and Effective Community Resilience

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Abstract: In this paper, we argue that an inclusive and effective community resilience approach requires empathy as a missing component in the current engineering education and practice. An inclusive and effective community resilience approach needs to be human-centric, individual- and communal-sensitive, justice-oriented, and values-based consistent. In this paper, we argue that three kinds of empathy, namely cognitive, affective, and conative, play a central role in creating and sustaining an inclusive and effective approach to community resilience. Finally, we discuss empathetic education through learning theories and analytics skills to cultivate empathy in engineering education. Cultivating empathy in engineering education could help advance the impact and contribution of engineering to well-being.

Keywords: empathy; community resilience; human infrastructure resilience; empathic design; justice; engineering education; engineering practice

1. Introduction

The number of recorded natural hazards (e.g., mass movements, volcanoes, landslides, earthquakes, floods, or extreme temperatures) in 2000 through 2018 was almost twice what it was in 1980 through 2000. During this period (i.e., 2000–2018), more than one million people lost their lives, and more than one billion people were severely affected by natural hazards [1]. The adverse impacts of natural hazards are not limited to the loss of lives, injuries, and destruction of built environments. These harsh events also affect the well-being of those in the affected community [2]. Such impacts of the natural hazards on individuals highlight the need to design systems that can face low-probability–high consequence events [3,4]. Resilience, defined as the capacity of a system to absorb disturbance and to recover to pre-disaster conditions, has shown to be a fundamental concept in mitigating the impacts of natural hazards [5,6].

Current approaches to designing resilient systems, however, have mainly focused on the performance of the physical-infrastructural systems, with a few exceptions addressing the specific needs of the individuals in the affected community [3]. Recent studies have shown that households in an affected community, especially vulnerable populations, are disproportionately impacted by disasters and experience more suffering due to destructive events [7,8]. These populations are highly exposed to the impact of hazards and have lower resources to respond to the adverse impact of disasters [9,10]. These populations are highly susceptible to the impact of hazards and have lower resources to respond to the adverse impact of disasters [9,10]. An inclusive approach to resilience design should aim at eliminating inequities present in the engineering system by considering interactions

between the human and the physical system. Such considerations call for new perspectives on how engineers design resilient systems. In this paper, we argue that an *empathic design* can bring about such a perspective.

In what follows, first, certain historic-conceptual reflections in engineering will be discussed, which leads us to the necessity of considering empathic design. Second, we elaborate on the physical and human-anthropological dimensions of community resilience and argue for four necessary characteristics of inclusive and effective community resilience. We show how empathy (in its three kinds of cognitive, affective, and conative) is part of a necessary response to those required characteristics of design for community resilience. Finally, in Section 3, relevant empathic engineering education theories and skills are proposed as solutions to incorporate empathy in engineering education for community resilience.

1.1. Need for Empathy in Engineering of Systems: Historical Reflections

Engineering is broadly defined as the creative application of empirical and technical science to design and development [11]. Design, in engineering, refers to a systematic process which aims at solving the identified problems regarding the existing materials and contextual constraints. The outcome of engineering design would be, in a broad sense, a system with desirable performance. It is also broadly considered that engineering systems' desirable performances should function as an instrument to realize human well-being, as the goal of engineering [12]. Thus, engineering systems are instrumental tools for well-being. The instrumental vision toward the engineering systems traced back to the traditional notion of engineering in the Middle Ages as well as Ancient Greece; the core idea of this traditional sense is the neutrality thesis of engineering. According to the neutrality thesis, engineering is a neutral instrument that can be used appropriately or inappropriately by users. The neutrality thesis was dominant until the early 20th century. Some global disasters, like the nuclear impact of World War II, in the early 20th century, changed perspectives on the nature of engineering and the relevant technologies. Some philosophers (e.g., Heidegger, Adorno, and Marcuse) criticized and undermined the neutrality thesis by referring to the ideological (i.e., social, cultural, political, or ecological) nature of modern engineering and technological developments [13].

Moreover, the nature of well-being per se as the goal of engineering has been investigated for a long period of time. Philosophers, psychologists, and social scientists addressed the important question of "what makes human life go well". In recent decades, it is largely conceptualized in terms of enjoyment, pleasure, human happiness, etc. [14,15]. Thus, in a general sense, it seems intuitive to state that well-being, as the objective of engineering systems, at least requires reducing human physical and mental suffering. If so, it seems that being a solution provider fits engineering goals, only if that solution helps in reducing the human suffering and not being neutral or even enhancing the condition in some ways. Moreover, as we shall discuss, empathic engineers are expected to be active in diagnosing human suffering issues and attempt to mitigate them. Based on this new perspective, being an engineer is not merely defined as a solution provider; rather, engineers should be problem diagnosters and attempt to reduce human suffering as well. The solution provider's point of view toward engineering has caused engineers in the field of civil and infrastructure to mainly focus on the physical performance of the systems during natural hazards. This approach would fail to acknowledge that the impacts of disasters are not restricted to physical damages, and the consideration of human anthropological dimensions is imperative in designing systems that address well-being. One of the main challenges of engineering is addressing human suffering, which impacts societal well-being [12].

In response to these humanistic considerations, engineering scientists have followed two main approaches to the interaction between humanities and engineering education. The first is the *a posterior* pragmatic approach, which refers to the study of the consequences of the engineering systems and productions. It holds that the application of humanity and moral imperatives function as the normative complement of engineering science and

technology. Some of the significant consequences of this approach can be observed in the development of most professional and ethical codes in a variety of engineering fields in the first half of the 20th century. Gradually, many of the thinkers figured out that engineering systems and productions are not neutral, and they have strong effects on moral, social, ecological, etc., dimensions of human life. So, they established some new fields of study like Science and Technology study, Technological Assessments, and Engineering Ethics [13]. The pragmatic approach addresses the following questions: how can we prevent the negative effects of technology on human life? What are the human and moral consequences of modern and complicated engineering systems? How can we imply those systems in realizing the humanistic and moral considerations?

The second is the *a priori* conceptual approach. In the second half of the 20th century, some of the contributors went deeper and held that the relationship between engineering systems and social concepts was not only on the pragmatic level, but there was also a meaningful epistemic or conceptual relationship between engineering design and social science. Since the 1980s, the concept of *sustainability* has been used, in a broad sense, to focus on preserving and maintaining the human, particularly for future generations focusing on justice and fairness [16–18]. Afterward, the concept of *resilience* was proposed as a necessary feature of an appropriate sustainable engineering system, referring to the reflective capability feature of a system [19,20].

This epistemic approach leads to the thesis of *empathic design*, which says engineers have to not only care about the humanistic consideration of technical dimensions in the pre-planning and design phases but also about others' feelings and thoughts during those preliminary phases [21,22]. Engineers need to see the problems not just from their own point of view, but they should perceive those problems from the lenses of the stakeholders engaging with the engineering systems. The pragmatic characteristics of engineering systems (which deal with the productions and consequences of engineering design) come from the more profound and more basic epistemic stage of identifying and knowing the pre-plans, plans, and designing process. The notion of empathy looks for a more fundamental concept which plays a central role in both sustainability and resilience. In the following sections, first, we discuss some necessary requirements of resilience. Secondly, we elaborate on the semantics of empathy and its characteristics, and thirdly, we will show why the latter is the necessary component of the former concepts.

1.2. Empathy: Definition and Characteristics

Empathy in psychology was considered as a research topic of experimental research in the early 20th century, and since then, it has been explored in several major fields of cognitive, developmental, social, and clinical psychology [23]. The new research on empathy as a major part of emotional intelligence in the late 20th century, however, made it a central concept in some significant psychological and psychotherapist research studies. Recently an increasing number of studies have been conducted on the role of empathy in engineering education [24–27] and practice [21,28–31].

In a general sense, empathy means the ability to understand other people's thoughts and feelings as well as the capacity of emotive treatment with them. It is emphasized in the literature that *awareness* is a necessary component of empathy, which distinguishes the concept of empathy from emotional contagion. "With empathy, the observer is aware that this feeling is a result of perceiving emotion in the other. With emotional contagion, the emotion is captured, but the observer lacks this awareness, and the observer believes this feeling to be his/her own" [23]. That is, psychological empathy is a result of a self-reflexive reflection and is not just an incident (Notice that there is a semantical similarity between empathy and some other concepts like sympathy and compassion; however, they are not the same. Sympathy has a more emotive meaning and refers to "a vicarious emotional reaction based on the apprehension of another's emotional state or situation, which involves feelings of sorrow or concern for the other" whereas compassion means

"the feeling that arises in witnessing another's suffering, and that motivates a subsequent desire to help" [32]).

According to its origins and functions, *empathy* can be categorized into the following three kinds: cognitive empathy, affective empathy, and conative empathy.

Cognitive empathy refers to the study of the ability and accuracy of the understanding of other people's thoughts in different contexts. Empathy, in this sense, is an epistemic tool to help us understand and know what others' minds are [33]. Some psychologists emphasize the congruency of the observer's empathic mental state with the mental state of the individuals who are the object of the empathic treatment, while some others deny the possibility of the complete congruency [23,34–36]. However, it is intuitive and largely plausible that cognitive empathy is not only available in some deep levels, but also, it is an indispensable part of our everyday life when we are talking or thinking about other people's thoughts, beliefs, and actions.

Affective empathy refers to the study of emotional responses of human beings to the encounter of others' conditions. Affective empathy is usually formed after the apprehension of other people's feelings and problems and sometimes entails some responsive actions. It can be thought of as the middle step, which is proceeded by cognitive empathy and would sometimes be followed by conative empathy, which is a professional and *pragmatic* tool in caring for other people [23,37–39]. Affective empathy is semantically close to sympathy.

Conative empathy refers to the study of the practical application of taking supportive actions in response to other people's feelings and problems. This kind of empathy is a professional and pragmatic concept, which refers to an empathic treatment with the people (like e.g., clients, stakeholders, or patients) in practice [23,40–43]. Conative empathy is the most apparent kind of empathy which would be fully objective and observable. It is also a necessary part of some clinical professions like psychologists and psychotherapists who apply it in assisting their patients. Conative empathy is logically preceded by affective and cognitive empathy. Accordingly, a comprehensive definition of empathy is an affective one which is originated from cognitive empathy and leads to a conative one.

1.3. Socio-Technical Resilience: Physical Infrastructure and Human-Anthropological

Engineering scholars defined resilience as "the ability to return to a stable equilibrium," or "the capacity of a system to absorb disturbance and re-organize while undergoing change so as to retain essentially still the same function, structure, identity, and feedbacks" [12]. Moreover, a resilient system has been shown to require adaptive and self-organization characteristics [5]. Traditional definitions and characteristics of resilience are more focused on the physical aspects of the systems. Recent studies in the literature have argued for the necessity of considering the human-anthropological dimensions of resilience, which refers to the humanistic dimensions and user and client of the system [12,44]. Even returning the status of a community as a system to the pre-disaster status condition may not be sufficient for reaching the ultimate objective of the system. The pre-disaster status naturally reproduces the current vulnerability [45–47]. Moreover, in many cases, the socio-technical systems' pre-disaster condition does not consider human dimensions. Thus, even if systems return to the previous status, they may not meet the needs of all individuals and may negatively impact some vulnerable groups in the communities [48–50].

This comprehensive approach to the concept, which is referred to as the resilience of socio-technical systems, includes two significant kinds of physical infrastructural resilience and human-individual resilience. Accordingly, socio-technical resilience is defined as: "the ability of a socio-technical system to keep or enhance desirable performances," and it "is a function of physical infrastructure resilience as well as of the individuals' capacity to deal with adverse conditions" [12]. It is believed that resilience should aim at enhancing human well-being by recovering the performance of the socio-technical system as a whole. A major challenge is developing models that can support both the resilience of socio-technical systems and human well-being [12]. This shows the need for a fundamental recognition of the system resilience, which accounts for humanistic consideration in addition to the physical

aspects. Such comprehensive understanding requires incorporating specific characteristics, which will be elaborated on in the following.

2. Inclusive and Effective Community Resilience and Empathic Design

An inclusive and effective approach to resilience design, which is supposed to satisfy both physical and humanistic dimensions, needs to be human-centric, individual and communal-sensitive, justice-oriented, and values-based consistent. As we shall show, these major characteristics of an inclusive model for community resilience need to turn from the pragmatic approach in engineering design to a more fundamentally epistemic one. The epistemic approach, as opposed to the current pragmatic approaches, enables interpretation of values, acknowledgment of varying human experiences, and considerations of human concepts (e.g., gender and racial minorities). Turning from the pragmatic level to the more fundamental epistemic level leads us to the significant issue of lacking empathy in engineering. As will be discussed in the following, empathic design, which is the outcome of embedding the empathic approach in resilience design, will meet all four critical features of any models which are supposed to satisfy both physical resilience and humanistic considerations. It holds that in addition to the technical knowledge, engineers have to care about the humanistic side of the engineering process as well. Accordingly, the empathic design is “researchers and designers moving towards end-users, of trying to get closer to their live[s] and work, of trying to empathize [sic] with them, with their experience and emotions” [30]. In what follows, we will elaborate on four significant characteristics of inclusive community resilience, and we shall show how empathic design fulfills them (see Figure 1).

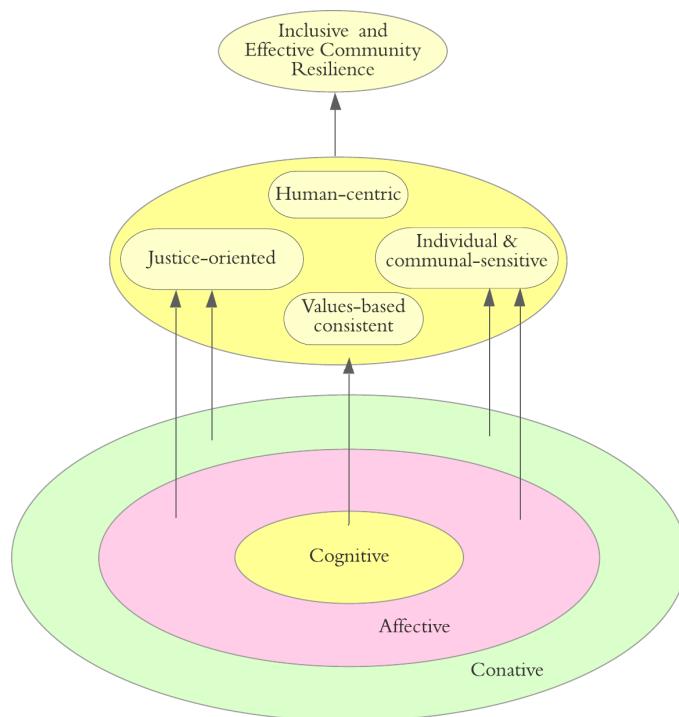


Figure 1. Conceptual model for the necessity of empathy as a pragmatic tool for achieving inclusive and effective community resilience.

2.1. Being Human-Centric

An effective resilience design would be human-centric in two senses, which both require cognitive empathy. First, community resilience has been recently defined in terms of recovering capability of stakeholders, which are affected by disaster and natural hazards [12]. In fact, the concept refers to returning the capability of those affected humans to their initial capability in the pre-disaster situation. Capability itself is modal philosophical

concepts, and more specifically, human capability is a psychological term as such. Therefore, a central part of resilience design would be related to the human side, which is in direct relation with the physical and infrastructural aspects.

Secondly, as discussed above, engineering aims at well-being and reducing human beings' suffering. It follows by necessity to consider human beings' real needs and problems, and design in a way that resolves those. Thus, a resilient engineering system should also aim at reducing human suffering, and this goal would be obtainable only if the humanistic sides of systems become "understood" by engineers.

This "understanding of the humanistic side" cannot be attained by implementing empirical approaches. This understanding is not limited to the physiological needs of the individuals; it is rather more relevant to subjective psychological and anthropological needs, other minds' feelings and experiences. Empathy as a "non-inferential and non-theoretical method of grasping the content of other minds became closely associated with the concept of understanding" [33]. Put in other words, cognitive empathy, as opposed to other empirical tools like experiments, has unique features that make a bridge between human subjective feelings, inferences, and interpretations about the outward world. So, a human-centric approach for designing resilient systems requires subjective epistemic tools like cognitive empathy.

2.2. Being Both Individual-Sensitive and Communal-Sensitive

Community resilience requires the recovery of the system's performance. It is broadly supposed that the engineering system resilience has to be considered at the community level. Recent studies have suggested that community resilience should consider the specific needs of individuals because the performance of a community is the function of its individuals [12]. However, community resilience is not simply a one-to-one function of its individuals' resilience; rather, there is another concept as communal resilience as well. Thus, the relation between the community and individuals should be explored to realize the resilience feature of a system. The collection and interaction among the individuals sometimes cause the emergence of some patterns at the community level, which cannot be seen just by looking at the individual level. Thus, an inclusive and efficient approach for designing resilient systems requires considering both individual and communal resilience, which both need different levels and kinds of empathy.

From a sociological point of view, there are two major theories on the semantic of the community proposed by Weber and Durkheim. Weber focuses more on individual autonomy in constructing the features of a society. Weberians believe that a community is a function of its individuals [51]. Durkheimians, on the contrary, propose that the features of a society are not equal to the one-to-one features of its individuals. A society is more than a simple aggregation of its individuals. He points out "social facts" as the distinguishing features of a society which are not reducible to individual-level facts [52]. For example, in a soccer team, the team's performance is not equal to the collection of each player's performance individually. The interaction among the team members plays a critical role in the final performance of the team in addition to their individual functions.

Paying attention to the major opposite differences between the two points of view of an individual and a communal level leads us to two important points on the concept of resilience. First, we cannot simply ignore the individual level in community resilience. There is a meaningful interaction between these two levels, and every impact on individual resilience affects the communal level and vice versa. Any inclusive model would meet the needs of each and all individuals of society and satisfies individual resilience, only if it follows a one-to-one stakeholders' comprehension and communication. Such a model enables both identifying their real needs and problems and foreseeing their future needs in probable disastrous situations.

Secondly, based on the Durkheimian theory of society, we cannot simply take community resilience like a *bijective* (one-to-one correspondence) function of individual resilience. That is, the study of resilience, as one feature of a community, is not equal to study of

individual resilience. For example, after a great depression in a society, it is not guaranteed that this communal depression will be removed after a successful recovery of all the individuals of that society, and it may take longer for the community to rebound the connections among the individuals to produce its communal level functions. It might be said that changes in society are greater and more lasting than changes in individual levels, and usually, it takes time to return society to the primary status before a disaster.

Moreover, it is not plausible to only consider one community resilience in each society because there are many sub-communities in a given society. Each sub-community has different values and capabilities, and some have overlap as well. Thus, it seems that any comprehensive model of community resilience must be both individual-sensitive and communal-sensitive and also consider all the major communities in a society.

Being individual-sensitive, which requires consideration of the needs of each and all individuals in the community, is equivalent to the human-centric approach, and therefore requires cognitive empathy, as discussed above. On the other hand, being communal-sensitive requires even deeper empathy. Being communal-sensitive requires two criteria: First, one needs to feel like an individual in that community. Secondly, it is essential to evoke the same feeling of the members of that community and maintain it for a long time in order to enable underrating the social fact. For example, one might understand what it means to be poor in a rich family. In such cases, it is probable that the poor person is not able to afford charges and always needs to borrow money from family members. However, living in a poor community has a different sense, which is not equal to the former feelings. In a poor community, in difficult situations, there is nobody to rely on, and this makes a great difference. Thus, to understand what it is like to live in a poor society, one needs to fully know and deeply experience the same feeling. Empathy provides this chance through *participant observations*. In this method, by applying conative empathy, you would act like a member of that community, and after a while, you will gain the same affections of that community (i.e., affective empathy), and it finally leads to understanding like a member of that community (i.e., cognitive empathy). That is, you need to empathically be involved in those communities and put yourself in their shoes for a while so you can also understand the social- and communal-level facts which are not equal to the individual ones.

2.3. Being Justice-Oriented

An inclusive community resilience aims at justice, which can be accounted for in three major moral approaches, all of which require three kinds of cognitive, affective, and conative empathy.

Community resilience is committed to bringing about human well-being, which refers to the well-being of each and all human individuals irrespective of their gender, sex, race, education, financial status, etc. Studies in vulnerability assessment of the communities have revealed that the socially vulnerable population experience higher hardship from natural hazards [53,54]. This has been shown to be rooted in individuals' higher exposure to the threats and their lower ability to tolerate the negative impacts [55]. The social inequities in the societal impacts of natural hazards suggest that current approaches have failed to meet the needs of the affected communities [4]. This highlights the importance of incorporating justice in designing resilient infrastructure systems. Therefore, an engineering system would be resilient only if it aims at justice and equally considers each and all individuals.

Three major moral accounts can be implemented for including justice in the resilience of the socio-technical system: First, Virtue ethics, which emphasize the subjective moral virtues; secondly, Deontology (or Kantian Ethics), which emphasize the duties and universal moral rules (i.e., categorical imperatives); and thirdly, consequentialism (or utilitarianism) which refers to the consequences of actions.

Given that community resilience requires each and all individuals to be helped, there could be three approaches to the necessity of such a humanistic consideration. First, according to Virtue ethics, community resilience has to be humanistic because helping other people comes from the human virtue of being benevolent and compassionate (i.e.,

referring to an agent's subjective moral character) [56]. Second, Kantian Ethics holds that we must help others because it is a universal moral rule, no matter what the characteristics of the agent are or what the consequence of the act could be [57]. Third, utilitarians believe that it is essential that each and all individuals are considered and assisted in a natural hazard because it ultimately maximizes the well-being of the community [58].

All these approaches highlight empathy in community resilience. The first two accounts lead to the Golden Rule, which says, "Others are to be treated by me as we would wish them to treat me" [59]. This, in turn, leads to conative empathy, which refers to the empathetic treatment of people based on cognitive and affective empathy. They both require human beings to think of other people like themselves, either as virtuous or as a moral duty. Moreover, the last utilitarian account also requires people to treat others fairly and empathetically without considering the actions as a kind of human virtuous or as a moral duty. According to utilitarianism, we need to treat others as we wished to be treated, empathetically, because it finally guarantees our ultimate interests in a social system. It holds that an engineering system would be effectively resilient in the long term, only if it really cares about justice. In other words, equity between individuals ultimately maximizes well-being for all the individuals, including those who are not affected too much by the disasters [58].

2.4. Being Values-Based Consistent

An inclusive, resilient system ought to be values-based consistent, while a values-based consistency will be fulfilled by cognitive empathy. It is largely considered that a resilient system has to be adaptive and must learn how to foresee the probable impacts during and after disasters. Foreseeing the potential impacts due to the disasters should be implemented in the engineering of infrastructure systems. However, achieving this objective would only be effectively obtained if it follows a value consistency between the designers and stakeholders. The designers and stakeholders, including both human resources of the infrastructure systems and human users, have different values and conceptualizations which have to be diagnosed, translated into a common language, and compromised. The different interpretation of a problem from different points of view, if not considered, prevents the outcome systems from achieving their objective in meeting the needs of individuals in the affected community. Such inconsistency in the fundamental value-level might cause some additional problems for the resiliency and sustainability of the system. For example, if the designers for local public transportation translate the ultimate goal of the system in terms of "expedition and speed," which is not committed to the "whole accessibility," the system would fail to meet the needs of the users, and this would also negatively affect the social justice.

Value consistency needs an understanding of other minds. Values include some conscious and unconscious concepts and beliefs in humans' minds, which are not necessarily communicated explicitly or correctly between the stakeholders. Discovering the correct formulation of all stakeholders requires the epistemic tool of cognitive empathy. This tool provides engineers with an understanding of the stakeholders' minds to enable them to incorporate those values in the resilience design of infrastructure systems.

3. Empathic Engineering Education Framework

In this section, we suggest an empathic engineering education framework that includes a set of four categories of learning theory and three categories of analytical skills.

3.1. Learning Theory Categories

Learning scientists conceptualize learning as the simultaneous processes of (a) knowledge construction and (b) becoming [60]. The first two learning theory categories—situated learning and transformative learning—are grounded in the conceptualization of learning as becoming. The last two learning categories are design-based learning and clinical engineering, both of which are grounded in a conceptualization of learning as construction.

3.1.1. Situated Learning

Situated learning theory describes learning as changes in patterns of participation in a community of practice as the learner increasingly identifies with and contributes to the community [61]. Relationships within communities are important, particularly the mentor-apprentice relationship. Vygotsky's [62] social constructivist theory describes learning within a zone of proximal development within which the learner can engage with ideas and processes beyond their current abilities, but only with assistance from a more knowledgeable peer or mentor. Designing zone of proximal development learning experiences requires scaffolding, with heavy scaffolding at the beginning followed by a gradual release of scaffolds as the learner becomes able to take on more agency and autonomy [63]. In engineering education, learners are not only becoming engineers within the community of engineering practice but also within multiple other communities [64].

We argue that engineering education should engage learners in work at the intersection of the engineering community and the communities for which they are developing engineering solutions. This aligns with Edelson & Reiser's [65] research which found engaging learners in authentic practices is crucial for powerful learning. Learner interaction with real-world stakeholders is necessary for development of cognitive (i.e., mind) and affective (i.e., heart) empathy skills. The authenticity of these stakeholder interactions is dependent on the nature of the interactions. Authenticity is low when the interactions are limited to collection of information and highest when the stakeholders and engineering students are co-equal collaborators in engineering research or development projects. Community-based participatory design [66] situates engineering education students as collaborators working in the intersection of the engineering and stakeholder communities. In short, learners need to work in the situation for which they are designing in order to engage in empathic engineering.

3.1.2. Transformative Learning

Transformative learning [67] describes one of the most powerful types of learning, one in which the learner's perspective is transformed. This perspective—frame of reference, assumptions, beliefs, and values—is the “form” which is transformed in transformative learning. Such changes in perspective can be characterized as epistemological (i.e., stances regarding the nature of knowledge and knowing) changes which typically follow a progression from categorical thinking, to cross-categorical thinking, to complex systems thinking, and finally to trans-complex systems thinking [68]. The design of learning experiences in empathic engineering education requires scaffolding to help students move along the progression of transformations of perspective because skipping stages in the progression is generally believed to be impossible.

At the individual level, epistemic cognition work involves metacognition—thinking about thinking [69,70]—but focuses on identifying and questioning assumptions rather than simply monitoring and regulating one's own thought processes. Helping engineering students develop metacognitive abilities can improve their interdisciplinary skills in general, and more specifically, to (1) overcome disciplinary barriers by revealing cognitive abilities and inabilities for each team member, (2) develop a deeper understanding of “wicked” problems that characterize disaster contexts in a more effective and creative manner, (3) collectively regulate team functioning, and (4) monitor and evaluate progress toward meeting project goals and objectives [71]. Here, we will argue and add that metacognition will help disaster research, specifically community resilience. Stakeholders themselves are an indispensable part of the infrastructure. Engineers have to know more about the human side of their systems not only in terms of interactions with stakeholders but also in terms of understanding infrastructure, *per se*, which includes human individuals [72]. Engineering students must learn to recognize, monitor, and evaluate their own thought processes (i.e., metacognitive skills) before they can understand the thought processes of other people (i.e., cognitive empathy).

Metacognitive work often involves observing one's own thought processes which are accessible at a conscious level. Epistemic cognition work pushes learners to go deeper by investigating beliefs, values, and assumptions which are usually not within our conscious awareness. Epistemic cognition is an integral aspect of transformative learning [68]. Both engineering educators and students must engage in explicit epistemic cognition work at the community or system level, interactional level, and individual level [73]. At the individual level, epistemic cognition is developed through metacognitive strategies such as reflection. Interactional level epistemic cognition development includes cognitive empathy work. In contrast to individual level (self, other individuals) epistemic cognition at the community or system level involves investigating assumptions, beliefs, and values distributed and embedded within larger structures such as communities, cultures, and systems.

The transformational learning strategy of epistemic cognition work at the individual level (i.e., understanding thought processes) can help cultivate cognitive empathy in engineering education. Work at the system level can help learners develop affective empathy and conative empathy when epistemic cognition focuses on identifying and analyzing the complex dynamics of power in the specific infrastructure context. This development of critical consciousness [74,75] provides a powerful bridge between cognitive empathy and empathy of heart and action because power dynamics create the perceived and real potentials for action on the part of any individual or group of individuals—actions which are key elements in the complex dynamic system and therefore determine both the range of possible emergent phenomena and the nature of the resilience in the system after phase transitions which may be prompted by disasters. Therefore, critical consciousness work is essential in developing justice-oriented engineering solutions for infrastructure and community resilience.

3.1.3. Design-Based Learning

Learning can be described not only as a process of becoming, as we saw through the lenses of situated learning and transformative learning theories, but also as a process of knowledge construction. Constructivist theory defines learning as the construction of knowledge within the mind of the learner [76] and collaborative or collective construction of knowledge [62]. Empathic engineering education operationalizes constructivist theory as designs for learning in which learners are taught to approach learning not as acquisition of knowledge or skills, but as collective, collaborative, and individual construction of knowledge. This transformation of perspectives by learners requires metacognition and epistemic cognition as discussed in the previous paragraphs, but also a change in their practices. Constructionist learning theory takes constructivist theory a step further by engaging learners in construction of things which reflect the knowledge they are constructing [77,78]. Constructionist learning activities set up positive feedback loops in which the construction of the artifact informs the construction of knowledge, which feeds back to inform the further construction of the artifacts.

Constructionist learning often takes the form of project-based learning. However, learners often need more scaffolding than is usually provided in typical project-based learning. The Design Thinking for Engaged Learning [79] was developed as a model for educators to structure project-based constructionist learning experiences. This model involves five design thinking phases (name and frame; diverge and converge; prepare and share; analyze and revise; and deploy) with an emphasis on developing designerly ways of knowing (i.e., cognitive strategies used by expert designers) such as empathetic thinking, reflection-in-action, and abductive reasoning throughout the process. The design thinking process and development of designerly ways of knowing engages learners in cognitive empathy work. This human-centered design work aligns with the human-centric and individual and communal-sensitive aspects of the empathic engineering framework. However, to incorporate the justice-oriented aspect of the framework and develop conative empathy skills, empathic engineering education incorporates the principles of universal design into designs for learning. The guiding principle of universal design is that by

designing for the most disadvantaged or disabled populations, we increase the quality of design for everyone. This guiding principle is translated into a set of seven design principles: (1) Equitable Use, (2) Flexibility in Use, (3) Simple and Intuitive Use, (4) Perceptible Information, (5) Tolerance for Error, (6) Low Physical Effort, and (7) Size and Space for Approach and Use [80].

Constructivist and constructionist learning situates learners as authors of knowledge rather than recipients, and the Design Thinking for Engaged Learning model situates learners as designers. Thus, the development of learner agency is an important aspect of the empathic engineering education framework. Helping engineering education students develop their own agency, autonomy, and authority results in increasing levels of engineering self-efficacy and intrinsic motivation [81,82]. We also argue that developing learner agency is essential for helping them move beyond cognitive empathy (mind) and affective empathy (heart) in order to do the hard work of empathy in action.

3.1.4. Clinical Engineering

For over a century, educational philosophers have problematized the artificial separation of learning from real-world work. For instance, Dewey [83] argued that learning is “a process of living and not a preparation for future living” (p. 7). As discussed in the previous sections, learning in empathic engineering education should be situated not only in the community of practice of engineering, but also in the communities in which engineering solutions and studies have impact. The transformation of engineering students’ frames of reference requires work in which they develop perspective-taking skills [84], particularly through real-world interaction with stakeholders who might otherwise be invisible in traditional methods of stakeholder analysis [74,75], or who are likely to experience the greatest negative impacts in disaster situations. This work could take the form of transdisciplinary sustainability science action research in which students engage in real-world engineering research characterized by students seeing themselves as practitioners working towards development as professionals enhancing their profession while empowering marginalized groups and leading social change [85].

Clinical engineering, which refers to a practical approach in cultivating empathy in engineering education, is derived from a comparative study between nurse study and engineering. Nurse study is one of the prominent fields of study which has cultivated empathy in practice and education. Since the 1990s, several empathy theories in nursing have evolved [86]. Empathy is conceptualized in nurse studies as a human trait, a professional state, a communication process, a caring process, and as a special relationship [87,88]. The central role of empathy in nurse study led to the development of empathic aspects in nursing programs and education [89].

Nursing and engineering, as two skillful professions, are both concerned with human welfare by helping people in solving their problems. Both nurses and engineers aim to increase their ability in the problem-solving process, and both need empathy as a primary tool in this process. However, engineers, as opposed to nurses, are often at a greater distance from stakeholders in their daily work and therefore, engineering education has paid less attention to empathy. We believe that engineers can, and ought to, learn many important lessons from nursing to improve their ability in empathic design and community resilience. According to [90] experimental studies, the measurement of empathy in nursing students is greater than that of engineering students. An engineer is more trained to be a solutions provider, while a nurse is usually trained to help patients in expressing their problems and diagnosing the patient’s problems in addition to assisting them in the healing process. Therefore, engineers are often considered as solutions providers, whereas nurses are expected to be problem diagnosers as well. Furthermore, engineers usually trust stakeholders in expressing what they really need, whereas the nurses are trained to go beyond what patients say in describing their needs or requesting particular treatments. They engage in empathic communication with the patient to diagnose the patient’s real need.

Nurse studies have made a great contribution to the understanding of how empathy can be cultivated. Studies have shown that empathic responses involve complex interactions between numerous variables including gender, culture, personality, interpersonal communication style, social confidence, and general communication skills [89]—variables which must be taken into account not only in theorizing about empathy, but also in developing empathic ability of nurses [87,91,92]. One of the major contributions of nurse studies in empathy was developing clinical training as a method for enhancing empathy levels in nurses. Comparing the nurse-patient relationship and engineer-stakeholders' relationship, we propose that clinical courses which require engineering students to actively contribute in helping stakeholders in some local and international hazards will effectively help in cultivating empathy in engineering education.

Clinical engineering involves not only engaging engineering students in real-world work with real-world stakeholders, but also frequent reflection activities in which they consider the meaning and impact of their current and future efforts [93]. In order for these activities to have optimal impact, they should be designed for identity exploration, including aspects of the reflective activities which regularly focus on promoting relevance, triggering exploration, scaffolding exploration, and facilitating a sense of safety [94]. Reflective activities in the context of clinical engineering facilitate development of cognitive and affective empathy, and real-world work dealing with real-world stakeholders to address authentic problems facilitates development of conative empathy.

3.2. Analytical Skill Categories

Empathic engineering education acknowledges the importance of helping engineering students develop skills in understanding themselves and the experiences of stakeholders through empathic work with real-world stakeholders in real-world contexts. Connecting the learning theory categories grounded in the construction and becoming conceptualizations of learning as described in the previous section are three categories of analysis: systems analysis, subjective analysis, and critical analysis.

3.2.1. Systems Analysis

In order to practice empathic engineering for the betterment of people's experiences and development of resiliency, engineering students must transform their epistemologies from categorical and simple systems thinking to complex systems thinking at the least, and ideally to trans-complex systems thinking [68]. Empathic engineering education develops engineering students' expertise in using tools for analysis of complex dynamic systems such as network analysis, systems thinking, and agent-based modeling. From childhood, human beings experience many instances of direct cause-and-effect events daily. As our experience is dominated by cause-and-effect events, we tend to develop linear cause-and-effect thinking which we apply to the analysis of all situations. However, not all situations can be adequately analyzed and explained in this modality of thinking. Community resilience in disaster situations is an example of one such situation—one which is more appropriately understood through complex dynamic systems methods such as network analysis and agent-based modeling [95,96]. Engineering students often work with complicated systems, but development of analytical skills for understanding truly complex systems can help them transform their epistemologies towards complex systems thinking and an ability to think beyond linear causality toward understanding emergent properties, emergent phenomena, system robustness, phase transitions, and other aspects of complex systems [97].

In empathic engineering education, engineering students engage in systems analysis to better understand the complex systems involved in the contexts in which they are conducting real-world analysis and problem-solving. This work addresses the systems level of communal-sensitive empathic engineering to compliment the individual sensitive human-centric aspects [98,99].

3.2.2. Subjective Analysis

Empathic engineering education is informed by human-centered design [100] analytical methods which are subjective in nature. As in all STEM fields, engineering education tends to focus on development of students' objective analytical skills, which puts them at a distinct disadvantage in being able to understand how real people subjectively experience the problems for which they are engineering solutions, or how people will experience those solutions. In Section 3.1.4, we discussed transdisciplinary sustainability science action research and clinical engineering in which students engage with real-world stakeholders around real problems. Some of the most useful analytical methods in this work are participant observation, conversation analysis, multimodal conversation analysis, content analysis, and interaction analysis [101]. Participant observation is the most demanding since it requires the engineering student to fully participate in the life and activities of the context under analysis, often requiring that the student lives in the context [102]. Development of skills in these subjective analysis methods is crucial for development of both cognitive and affective empathy, and a means of operationalizing the human-centric, individual-sensitive, and communal-sensitive aspects of empathic engineering.

3.2.3. Critical Analysis

Understanding the complex systems and subjective experience of individuals and communities is an important—but insufficient in itself—part of empathic engineering education. A third category of analytical skill is also required: critical analysis. Systems analysis and subjective analysis skill development will help engineering students develop cognitive and affective empathy, but in order to translate empathic understanding into meaningful engineering work (i.e., empathy in action), the empathic understanding must be accompanied by critical analysis of assumptions, perspectives, values, and frames operating within the context of the engineering work at hand—particularly those which result in marginalization, oppression, or other forms of often invisible suffering. There are a number of powerful critical analysis methods, including frame analysis [103], discourse analysis [104,105], and critical pedagogy [75,106]. In frame analysis, the researcher seeks to uncover and describe underlying assumptions—assumptions which are usually not even within conscious awareness of individuals involved in the context being analyzed [103] and therefore require not only facilitation of discussions to uncover assumptions, but also a great deal of reflection by the researcher [107]. Another method of uncovering and describing assumptions is discourse analysis in which the researcher analyzes an utterance as it is situated in context, in relation to other utterances, how the utterance would be interpreted in different contexts or from different perspectives, the mindset in which the utterance was made, the framework (e.g., mental models, figured worlds, discourse models, cultural models, informal theories, etc.) in the context of the utterance, what the utterance might mean from the perspective of a different framework, and negotiation of the meaning of the utterance with other researchers and stakeholders [104,105].

Another powerful critical analysis methodology is deconstruction. Fixed and determined constructed concepts in human minds entail towards injustice. Some opposing concepts such as Black/White and man/woman act as our lenses toward the outside world. These lenses directly impact our interpretation of the world around us and often prevent us from seeing different phenomena without the mediation of these fixed concepts. Therefore, they may lead to a lack of empathy in our interpretation of distinctive phenomena because they rely on categorization of many distinctive concepts into one group. Derrida's deconstruction theory can help us to cultivate cognitive empathy in engineering education. Derrida believed that such fixed, determined conceptual categorizations have entailed injustice [108]. According to his philosophy, "deconstruction is a criticism of Platonism, which is defined by the belief that existence is structured in terms of oppositions (i.e., separate substances or forms) and that the oppositions are hierarchical, with one side of the opposition being more valuable than the other" [108]. Derrida's deconstruction aims at dismantling the constructed concepts in our mind, particularly dualities such as Black/White,

man/woman, normal/abnormal, or enabled/disabled to make room for justice to flourish. Such conceptualizations of other people and how they experience their world prevents us from being genuinely empathic and understanding of their feelings, suffering, needs, and thoughts. Derrida proposes that we must deconstruct these constructed concepts and try to look at the human being, in a phenomenological way, as an end for itself, not through these constructed and fabricated concepts.

In order to cultivate empathy in engineering through deconstruction, we have to engage engineering students in two analytical approaches. The first approach is proposing an alternative. Here, we introduce another neutral concept alongside dual constructed concepts. This approach enables the deconstructing of previous conceptual constructions. For example, designing for children is a neutral concept in the conflict between feminine and masculine systems of engineering. Emphasizing children's needs in designing a civil infrastructure will help us to deconstruct the existing sexist constructed values in infrastructure engineering. Similarly, designs aimed at the next generation's well-being will deconstruct the conflict between past and present generations inherent in some conservative and progressive approaches in civil engineering.

The second deconstruction analytical approach is reversing the conceptualization. In this approach, engineers attribute higher value to concepts and groups which have been historically marginalized, and attribute lower credit to those concepts and their relevant groups which have been privileged through existing conceptual constructions. This approach helps to deconstruct and change existing value systems. Deconstruction helps us see the phenomena from a different perspective and directly avoid our selfish and dogmatic approaches, thus cultivating our empathy. It enables engineers to put themselves in other people's situations and try to think like them, believe like them, and act according to their thoughts and beliefs. For example, most engineered systems aim at serving "normal" people. Applying this deconstructive approach, we educate engineers to design systems like public transportation, firstly, for disabled people and secondly, try to design it such that it would be beneficial for other people as well. Through this way, we not only put disabled people in the canon of our engineering system and help them in developing their ability in a biased society, but also help other people to reframe their values about disabled people around them in a society. The deconstruction analytical approach of reversing the conceptualization is aligned with the principles of universal design mentioned in a previous section [80].

Another example of the issue of constructed lenses in design is the problems experienced by people with short stature. In most buildings, the stairs, elevators, bathroom sinks, water dispensers, and many other systems have not been designed for them but designed to serve people of "normal" height. In hazardous situations, they face more problems and challenges. If an engineering designer deconstructs this "normal/abnormal" conceptual construction, they can simply design, for example, two buttons for an elevator—one for people with short stature and one for other people. However, until recently, we rarely saw such designs in elevators. According to Derridean theory, the reason is that dual categories are constructed in our minds in which "normal" people have a height of around 170–180 cm, and people of other heights are "abnormal". In empathic engineering education, we engage students in deconstructing dominant concentrated descriptive concepts in our minds to gain empathy and reach justice. By engaging in deconstruction and universal design, we both help previously marginalized members of society have the sense of being recognized in society and help other non-marginalized people to contemplate the natural differences between people in a society, thus directly cultivating different kinds of empathy in our society.

Critical pedagogy is another critical analysis method that is used in empathic engineering education. This analytical method is related to deconstruction but adds the element of engaging learners in analysis of power, with a particular focus on the margins [75]. One of the key principles of critical pedagogy is guiding students in analyzing and problematizing dominant ontological and epistemological stances, especially regarding the ways in which

positivism serves to reproduce oppression, marginalization, and inhibiting development of an individual sense of agency and authority [75,106]. Another principle of critical pedagogy is the development of praxis, which Friere [74] defined as simultaneous reflection and action upon the world toward reframing, renegotiating, and deconstructing systems and relationships of power.

3.3. Interdependence in the Empathic Engineering Education Framework

The empathic engineering education framework requires that designs for learning incorporate all the elements discussed above in the learning theory and analytical skill categories (see Figure 2) in an integrative manner. These elements are mutually dependent and focusing on some elements more than others—or neglecting any particular element—may result in less than optimal development of empathic engineering.

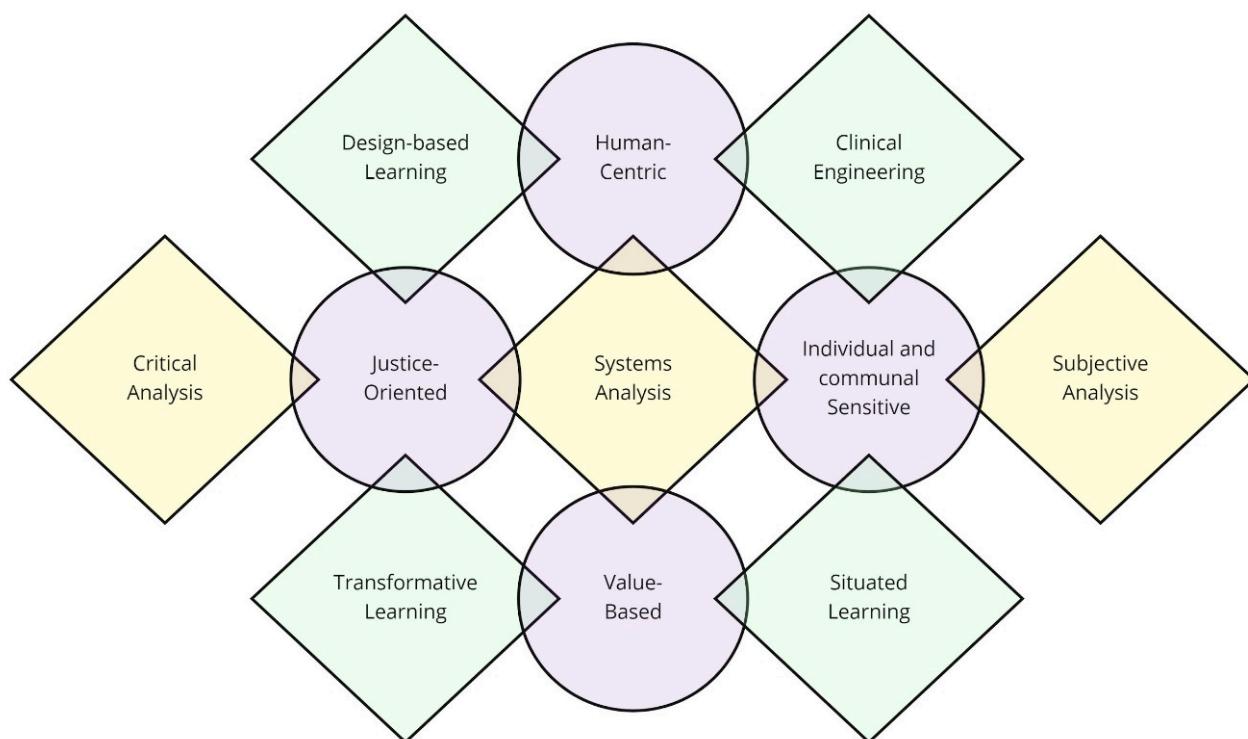


Figure 2. The empathic engineering education framework.

In optimal empathic engineering education, learners participate in engineering and contextual communities (situated learning) while engaging with real-world stakeholders (clinical engineers) to understand their unique individual experiences (subjective analysis) and the complex dynamic systems in the context (systems analysis) to solve real problems (design-based learning) from a human-centered and critical perspective (critical analysis) which transforms their frames of reference and epistemologies (transformative learning).

4. Conclusions

This paper introduced empathy as an essential tool for engineers to enhance the resilience design of the communities. Empathic design enables infrastructure systems to be human-centric, both individual-sensitive and communal-sensitive, justice-oriented, and values-based consistent, which are four critical characteristics of a resilient system. Current approaches in designing engineering systems have failed to meet the humanistic consideration in modern societies. Ethical codes, sustainability, and community resilience each have taken some vital steps toward the goal of engineering which is human welfare in general and reducing human suffering, as one of the preliminary steps toward human

well-being. The empathic design has been introduced as a solution for solving such issues and consider the humanistic aspects into the design of the engineering systems.

The advantage of using this approach is not limited to its contribution to improving community resilience. Thus, we believe that empathic approach as an *a priori* approach toward engineering not only effectively helps sustainability and community resilience but also has the capability to be considered as the new concepts which are derived from the necessary interaction between engineering study and humanity. Empathic engineering, which is developed through situated learning, transformative learning, design-based learning, and clinical engineering along with subjective, systems, and critical analysis, requires the engineers to revisit the existing or pre-disaster exciting engineering system and change them, such that to being fully human-centered, justice-oriented, individual- and communal-sensitive. By implementing this approach, we might make a conceptual paradigm shift in engineering education and enable the better realization of human well-being as the main objective of engineering for sustainable and resilient communities.

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