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A Holistic Education for the 21st Century Engineer Based on Wisdom and Multiplexity

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Abstract. In a volatile, uncertain, complex, and ambiguous (VUCA) 21st-century world, there is a great need for drawing upon capacity for holistic thinking and wisdom. We need to leverage multiple transdisciplinary thinking that allows a multiplexity of ways of thinking and knowing to deal with multi-layered complex reality. Our society is rife with elusive "wicked problems" that defy narrow technological solutions emerging from disciplinary siloed thinking. A narrow education in such times is not only sub-optimal but also dangerous. With the advancement in artificial intelligence, we now have too advanced a technology to be able to survive without wisdom. We require a broad range of experiences and models to study the same problem and the wisdom to choose and combine different models in appropriate ways. We need not only mathematics, engineering, and sciences for engineers but also an exposure to the important ideas in philosophy, psychology, history, economics, sustainability, and significant insights about subjects of enduring interest to human beings.

Keywords. Transdisciplinarity, Engineering Education, Wisdom, Phronesis, Multiplexity.

Introduction

"*We are now far too clever to be able to survive without wisdom*."— Schumacher [1].

We live in a very interesting time in history where we find great opportunity to leverage unprecedented technology for doing great social good while also seeing too often that technology when not guided by wisdom can result in antisocial phenomena. While technology promises to connect us, it often ends up polarizing people. While technology and information and communication technology (ICT) can enable a level playing ground for all, it often ends up amplifying inequalities; experts have pointed out that technology amplifies human intent, purposes, and systemic forces and this can work for both social good and social harm [2]. Thus, technology alone will not solve our problems [2] [3]. The technology critic Neil Postman wrote, "*it is a mistake to suppose that any technological innovation has a one-sided effect. Every technology is both a burden and a blessing; not either-or, but this-and-that*" [4]. Unguided technology can result in aiding and amplifying oppression [5] [6].

Most of the grand engineering problems that the society faces (poverty, inequality, racism) are actually systemic social problems in which there are vested interests that may be amplified by technology. Such problems have been dubbed as "*wicked problems*" as these problems defy intuition and technological solutions. We cannot shift the burden of thinking about our higher social values and figuring out our society's *summum bonum* to technology due to the possibility of narrow vested interests (e.g., potential manipulative practices by corporations that depend on surveillance capitalism to further their commercial interests [7]). We also need to create systems that lead to a thriving open global civilization that places a premium on the universal interest of the welfare of human beings (spiritual as well as material). Many of the problems in the modern world emerge from the use of a one-size-fits-all style of thinking that ignores the diversity of human beings and trying to globally enforce the hegemony of Western Euro-centric ways of thinking.

This paper makes the case that we need to bring wisdom to center stage as we contemplate the holistic education of a 21st century engineer. In the remaining paper, we describe how we lack two kinds of wisdom. The *first kind of wisdom that we lack is* ***theoretical wisdom*** that results from the adoption of "Uniplexity" rather than "Multiplexity". We refer to Uniplexity as the thinking that reduces multi-layered reality and traditional ontologies and epistemologies to a single-dimensional way of thinking that is typically associated with Western science (based on materialism and positivism). With the dramatic increase in the potency of modern technology at the disposal of engineers, it is vital that these technologies are put to use for good and service to humanity at large. For bringing wisdom back into mainstream, it is important to highlight the cause (Uniplexity) that led to its streamlining of wisdom in the first place. We discuss Uniplexity, its causes, and harmful consequences are described in Section 1. Instead of focusing only on empirical methods and technology at the cost of exclusion of all other methods as is common in engineering sciences, we need to adopt Multiplexity (introduced and discussed in Section 2) in which multi-layered reality is assumed and analysis is done using epistemologies appropriate for the the task at hand are utilized. The *second kind of wisdom that we lack is* ***practical wisdom*** due to which knowledge and engineering is pursued without sufficient focus on practical wisdom and higher purposes. Thus, wisdom is not needed just in theoretical but also in practical pursuits. We need wisdom in understanding nature (scientific endeavors), molding nature (engineering endeavors), and using tools (technological use).

1. The Problems of Uniplexity

Many of the problems we see in our society today stem from a narrow approach to phenomena, which we refer to "Uniplexity" following the lead of Şentürk [8]. This typically stems from a reductive approach in which positivist methodology is used in natural as well as human and social sciences. This approach takes the reductionist route of favoring one methodology or model to all other approaches for all phenomena (material or human or social). Uniplexity extrapolates the success of Western science in solving physical mechanical problems and imagines the same methods can also be applied in all domains including the human and social domains. While some reductionism is inevitable for doing analysis, when taken to an exclusivist (nothing-but) extreme, Uniplexity disables us from dealing with reality in a holistic way.

A major loss through the adoption of Uniplex methods has been the sideling of the fields of ethics (the study of virtue and vice and what is morally right and wrong) and axiology (the study of what one ought to do). Values and ethics are normative and thus were deemed non-scientific and thus not part of knowledge [9]. Since wisdom is inevitably related with value judgements and cannot be reduced to a formula, it also became sidelined under Uniplexity. However, in the volatile, uncertain, complex, and ambiguous times that we live, it becomes ever more important to leverage insights from the wisdom tradition. As E.F. Schumacher points out that a society that does not perform a sustained study of the so-called "unscientific" questions (such as: What is the purpose of human's existence? What is good and what is evil? What are main's absolute rights and duties?) is guaranteed to sink necessarily and inescapably deeper into anguish, despair, and lack of freedom [1].

Another aspect of Uniplexity is the reduction of all knowledge to science (based on numbers and facts) and the purpose of science to solely the control and manipulation of nature without any real concerns with virtue, reality, beauty, and truth. This has resulted in very smart people doing evil things much more efficiently resulting in the negative channelization of intellectual knowledge [9]. In such a context, the social ills of computing and engineering technology cannot be mitigated solely through the addition of new ethics courses or through more advanced technology.

Computing and engineering technology is now integrated into the very fabric around which the modern society is weaved. It is no longer satisfactory to analyze such systems and algorithms in isolation using standard technical analysis methods. Since human societies in which engineering technologies are deployed are complex adaptive systems, engineering interventions cannot be merely analyzed in isolation purely on quantitative terms. There are numerous examples of the counterintuitive nature of social systems and how intervening in systems have long-term hard to predict results. Context matters, especially in complex social systems [10]. The Uniplex method works by reducing the system into small entities working in isolation but the reduction of multi-layered reality to just physical material phenomena and forcing a false dichotomy of how we can learn new knowledge (e.g., *empirically* using science or *ideally* using mind and reason).

Albert Einstein is reported to have said, "*we cannot solve our problems with the same thinking we used when we created them*." To solve the problems created by Uniplex thinking, we need to move away from Uniplex thinking. We must now study how computing systems are affecting the human society using the various methods used in the humanities and the social sciences [11]. The multiplex approach allows the marriage and integration of different epistemologies in which different ways of knowing are used appropriate in their proper place. For studying social phenomena, we need a combination of empirical methods and normative methods. Various experts are now highlighting how in the light of greater uncertainty around the potential benefits and harms of modern technology, it has become important to highlight the importance of character education and emphasize virtues in how technology is designed and used [6] [12].

Uniplexity also manifests itself through Eurocentrism inherent in Western social science [9]. This has led to the problems of a Eurocentric bias in socio-technical artifacts[1] and in the marginalization of the global diversity in important discourse such as coming up with codes of ethics for regulating AI[2]. This results in the problem of monoculture and has led to a perception that the Western Social Science is universal and that it can be uncritically applied globally as it is. Multiplexity allows us to pursue knowledge for its own sake and for attaining virtuous ends and not only for control.

1 https://www.nytimes.com/2016/06/26/opinion/sunday/artificial-intelligences-white-guy-problem.html
2 https://www.sefi.be/2022/02/02/ethics-in-engineering-education-and-practice-assessing-the-state-of-the-art/

Uniplexity has also enabled the formation of silos with its emphasis on analyzing parts in isolation and not focusing on the big picture. This has resulted in artificial boundaries between various academic disciplines as noted by Ackoff and Emery, "*Nature does not come to us in disciplinary form. Phenomena are not physical, chemical, biological, and so on. The disciplines are the ways we study phenomena; they emerge from points of view, not from what is viewed. Hence the disciplinary nature of science is a filing system of knowledge. Its organization is not to be confused with the organization of nature itself.*" [13]

The approach of Multiplexity also can help bridge the disconnection between scientists and the experts in humanities and the lack of interfacing was highlighted by C. P. Snow in [14] by giving credibility to multiple methods in their proper domains. This can help us see through the Multiplexity allows us to see how phenomena are transdisciplinary and reward a better understanding through synthesis and integration of diverse methods. The multiplex methodology allows critical understanding of the underlying (often tacit) assumptions of methods while allowing openness through which false dichotomies can be avoided where possible. This allows us to benefit from diversity, which has been shown by experts to be very beneficial as it allows to us remove blind spots and come up with better models of reality [15] [16] [17].

Even though many works have been written on the harms of reductionist science and engineering, these have traditionally focused on the critique that modern methods look at things in isolation without taking the whole system in view or by seeing the long-term effects of actions. Our work complements this critique by highlighting that the reduction can not only occur *horizontally* (focusing on a subsystem or a slice of time without looking at the big picture) as well as *vertically* (focusing on just some aspects of reality and ignoring other aspects completely). We also highlight that diverse methodology can be used in parallel in their own respective niches.

Try as we might, it is not possible to completely eliminate subjectivity and values and it is better to articulate and understand the underlying values rather than aiming for a value-neutral science (that nonetheless has embedded a certain philosophical value system) [18]. Using Multiplexity, we don't have to choose between objectivity and normativity—we become more accepting of the fact that we cannot separate objectivity from subjectivity and normativity and good science requires us to be clear in our assumptions and critical about what we exclude and include in our thinking framework.

We need a holistic multiplex methodology, which differentiates between the various domains of knowledge (material, human, societal) and incorporates intellectual moral wisdom (ethics and normative stances) as well as practical moral wisdom (including virtue habituation).

2. Multiplexity

Multiplexity defines a comprehensive approach that recognizes each layer of reality. Multiplexity aims to do the elusive task of combining the quantitative and qualitative and the objective as well as the normative. There are different kinds of multiplexity. One particular way multiplexity can manifest itself is through multiplicity and relativism, where plurality is based on competition.

There is another more holistic approach proposed by Şentürk et al. [8]. Şentürk et al. refer to Ibn Khaldun and Al-Farabi as philosophers who followed a multiplex approach. It proposes multiple methods suitable for each layer of reality to do justice to reality.

Even though we refer to the approach proposed by Şentürk et al., this approach is not exclusivist or something unheard. Most of the Eastern and the Western traditions believed had a multiplex understanding of reality and incorporated a belief in different levels of existence (*ontology*); diverse ways of knowing (*epistemology*); ways of finding out new knowledge (*methodology*).

Multiplexity is derived from the age-old Arabic term '*marātib*' which literally means hierarchy or levels. Şentürk et al. devised the term "multiplexity" to refer to the multiple levels of existence, known as *marāṭib al-wujūd*, knowledge and truth [8]. In social research, multiplexity would indicate a concept of the human being consisting of body, mind, and soul as well as a concept of social action at various observable and unobservable levels. The basic paradigm of positivist and idealist (constructivist) inquiry and the difference between their ontology, epistemology, and methodology is provided by Şentürk et al. in [8]. The book also mentions how the Multiplexity approach is able to avoid false dichotomies and open up an open system for knowledge.

By exploring the literature, we find that the understanding that reality is multi-layered a widely shared one. We see references to hierarchical levels and paradigms in various works. For instance, Jantsch in a classic paper on inter- and transdisciplinary university system talked about the education/innovation ecosystem as a multi-level multi-goal hierarchical system [19]. The "empirical level" of this system can be studied using empirical methods and logic. However, this is a higher "pragmatic level" which is better studied by analyzing the natural and social ecology using methods such as cybernetics that consider feedback in the system. There is then a higher "normative level" which deals with values and is properly studied and interfaced with planning. Finally, there is a "purpose level" that deals with final ends, purposes, meanings, and value, and this is best studied using the methods of anthropology and not with just empirical methods. The field of *engineering* is inherently one in which we intervene in the physical world and modify it for the benefit of people. Systems thinking pioneer Donella Meadows provided a hierarchy in which described quantities (constants, parameters, numbers) are among the least effective place to intervene in a system with the most effective places being those that relate to the goals of the system and the mindset or paradigm of which the system – and its goals, power structure, rules, and culture – arises [20].

Aristotle is reported to have written in *Nicomachean Ethics (Book I, 1094b.24), "It is the mark of an educated man to look for precision in each class of things just so far as the nature of the subject admits; it is evidently equally foolish to accept probable reasoning from a mathematician and to demand from a rhetorician scientific proof."*

Einstein is also reported to have said that "*a new type of thinking is essential if mankind is to survive and move toward higher levels*."—implying that we cannot solve our problems created by our way of thinking with the same kind of thinking.

Multiplexity allows for combining techniques and methods from humanities and sciences and engineering for study and analyzing different aspects of the human and social reality. This is a key ingredient for attaining wisdom as Sternberg argues in his book chapter that it is profitable to benefit from insights available in the field of humanities, which is where wise thinking is most likely to be taught in the modern universities [21]. Multiplexity is aligned with the goal of wisdom, which can be approached by looking at transdisciplinary phenomena through a latticework of mental models as proposed by Charles Munger [22] [23].

It is important to note that Multiplexity does not preclude gradation and varying ranks of knowledge. In fact, this is one of the key aspects of what distinguished it from

Uniplexity. Multiplexity accommodates space for certain knowledge and also for probabilistic knowledge. It even accommodates for learning insights from religious knowledge and its application at appropriate realms related to purpose, values, and ethics. Multiplexity also allows finding the right middle approach between extremes (*this* or *that*). For example, in the history of AI, good old-fashioned AI (GOFAI) tried the way of logic, while recent methods are based on empirical induction and learning from data. The method of Multiplexity would allow combining both approaches in a hybrid fashion instead of looking for solution in any one approach since there are situations in which one situation is much better suited than the others.

Multiplexity allows for integration and synthesis of multiple models. When there is one perfect model, it will eventually be accepted. However, if the chosen model is one of the many imperfect yet useful models, it may be expected that competing models will remain and that all of them would continue to be useful together. We find a need for such multiple-model thinking even at very fundamental level of physics — for instance, Bohr's model of light is it can be viewed both as a particle and as a wave, just never at the same time. In this way, opposing models can complement and strengthen each other allowing *synthesis* of two competing hypothesis (*thesis* and *antithesis*, a la Goethe). The method of Multiplexity is open to interdisciplinary work and in this regard can benefit from the body of knowledge surveyed by Bammer, who describes the effort of the community focused on Integration and Implementation Sciences, which is an effort on systemizing the methods necessary for interdisciplinary work [24].

Multiplexity allows the development of greater understanding through dialectical thinking. In this way, it can allow greater synthesis of Easter and Western methodologies. Logical-Mathematical is not the only kind of intelligence. Psychologist Richard Nisbett has shown in his research that Western world is by and large focused on logic as its main pillar compared to the East, where the dialectical method is more commonplace; the Eastern thought is also focused on the middle way between extreme propositions [25]. Nisbett writes in his book [25] comparing the merits of Western and Eastern thought, *"Western thought is analytic and emphasizes logical concepts of identity and insistence on noncontradiction; Eastern thought is holistic and encourages recognition of change and acceptance of contradiction."* and *"Eastern thought produces more accurate beliefs about some aspects of the world and the causes of human behavior than Western thought. Eastern thought prompts attention to the contextual factors influencing the behavior of objects and humans. It also prompts recognition of the likelihood of change in all kinds of processes and in individuals."* and *"But I'll stick my neck out and hazard the generalization that logical thinking is crucial for scientific thought and some kinds of well-defined problems. Dialectical thinking is often more helpful for thinking about everyday problems, especially those involving human relations."*

As Howard Gardner elaborates in his theory of multiple intelligence, we are able to understand, solve problems, and create things not just logically but using a myriad other intelligences (including interpersonal, intrapersonal, etc.) [26]. A lot of engineering education is focused on developing logical and mathematical capabilities emphasizing mind over heart (emotional intelligence) and body (embodied knowing) [27][28]. The focus on affective domain is especially important when we wish to change and transform the behavior of engineers through engineering education so that they become more compassionate and incline towards virtuous behavior and performing social good.

3. Wisdom and Engineering Education

Various 21st century engineering education efforts have highlighted the importance of wisdom and a broad-based holistic education for modern engineers at a time where new knowledge is produced at an unprecedented pace, and we have control over very powerful technologies [29] [30-33] [34]. Apart from cognitive skills, 21st century engineers must also develop phronesis, which can be defined as "*wisdom in determining ends and the means of attaining them, practical understanding, sound judgment.*" [35] A lot of attention has recently focused on studying practical wisdom on a scientific basis [12] [36] [37] and on training practitioners with the skill of practical wisdom (also called *phronesis*) [35] [38].

Engineering in the Pursuit of Higher Purposes: It is pertinent to keep in mind a definition of engineering offered by Chris Wise, *"Engineering is the art and practice of changing the physical world for the use and benefit for all."* It is important to inculcate the practical wisdom that enables all engineers to work towards ends that are beneficial for all humanity especially in modern times where engineers are very rich in means and offer clueless about ends. Wisdom is also distinguished from cleverness in that it is aimed at virtue and social good [12] [39]. We note that Peterson and Seligman have defined wisdom as "*knowledge hard fought for, and then used for good*." [39]. Experience with customized recommendations on the Internet and the resulting problems (outrage, polarization, filter bubbles) has shown that satisfying all their desires is not necessarily the best way to design a flourishing society. Following the selfish concerns of the ego does not necessarily translate into greater social welfare. This wisdom also applies to artificial systems. Stuart Russel quotes Norbert Weiner in his book and cites the Greek mythical story of King Midas to highlight why AI should be aligned with human values and not focused only on optimization (since machines do not have values of their own) [40]. We must also differentiate between base and higher desires as has traditionally been done in the wisdom literature. Bringing wisdom to engineers would require equipping them with the wherewithal to strive for higher purposes (aiming for bringing welfare to all humanity and pursuing truth and virtue). Training for wisdom also requires a mindset that is not detached from truth and reality and is not focused merely on defending one's current belief like a soldier but who like a scout is always interested in learning and making better maps of knowledge [41].

Recognizing the Limits of Tools and Models: Models and methods prime our mind to think in a particular way or to focus on a particular dimension resulting consequently in the neglect of other facts and perspectives. It is important therefore to be aware of the boundaries, limits and drawbacks of each theory, model, and method [42] [43]. As highlighted earlier, technologies are both blessings and a burden. We should be able to critically evaluate the technology and anticipate the potential pitfalls and negative consequences of the use of a technology. In the field of medical science, there is a term called *iatrogenics*, which refers to the wounds that the healer gave. Analogously, many of the modern problems we face today are unanticipated results of technological solutions of yesteryears. Being wise to this possibility requires us to critically evaluate our technological solutions with falling prey to the "*Pygamalion effect*". We should also be aware of extrapolating a model beyond the region of fit [42]—an example of this would be to assume uncritically that Western/European viewpoints on social issues apply globally without fail or need for modification. This wisdom is enhanced by training engineers to be reflective engineers who critically evaluate their practice to see what is working and what is not [44] [45] [46]. Engineers must also reflect on the philosophical underpinnings of their field and which ontological and epistemological commitments are implicit in their methods. This will enable engineers to evaluate if they are holistically analyzing the overall system or if they are falling into the trap of unwarranted reductionism.

Wisdom Can't Be Told: Wisdom is Not Formulaic: Sternberg describes how the problems considered in school education are different from complex problems, whose solution requires wisdom [21]. Put simply, complexity demands wisdom and wisdom requires practice [21] [38]. Sometimes wisdom implies increasing possibilities (where creativity is required) and sometime in reducing the set of possibilities (when integration is required). Sometimes wisdom lies in removing conflicts or in dissolving problems [47]. It is commonly accepted that wisdom cannot be broken down into a formula that will work all of the time. Sometimes wisdom lies in managing divergent models through a dialectic process for marshaling differences and complexities on the way to better solutions [48]. In this regard, design thinking can be used to encourage divergent thinking that is necessary for design to complement the convergent thinking common in engineering discipline [49]. To elaborate, insights from two experts are provided next. Donald Schön describes how the high hard ground where practitioners can make effective use of their techniques is quite distinct from "*swampy lowlands*", which represent messes incapable of technical solution and require critical reflection [46]. David A. Freedman highlights how statistical methods (upon which modern data science and machine learning is based) is seldom an adequate substitute for good research design, relevant data, and expending of "*shoe leather*" testing predictions against reality in a wide variety of settings [50]. This is the reason why apprenticeship, internships, and case studies are methods of choice for exposing students to authentic experiences from which the students can learn insights after reflection to guide future practice [51]. Although not formulaic, engineering education can benefit from the insights gather by researchers reported in [52] on educating for wisdom.

4. Conclusion

In this paper, a perspective is provided on why the education of 21st century engineer is incomplete if a narrow technical education is provided that does not encompass appropriate training for deploying multiple methods and methodology according to the task for which these will be deployed. Furthermore, we have highlighted the problems arising from Uniplexity, which is a reductionist knowledge system that suffers from one-size-fits-all epistemology and methodology that is not sufficiently nuanced for the modern volatile, uncertain, complex, and ambiguous world. We propose the use of Multiplexity that combines multiple model thinking with an openness to diverse epistemologies and attempts to integrate and apply these methods in their appropriate places. Furthermore, we highlight the need for theoretical wisdom (through a focus on Multiplexity rather than Uniplexity) and practical wisdom by embracing phronesis and through the pursuit of virtue and higher salutary purposes.

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