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REVIEW ARTICLE

Imaginary, knowledge and norms: Triple essentials in engineering education

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ABSTRACT

Engineering practice encompasses threefold root: imaginary, knowledge, and norms. Consequently, engineering practitioners must have ability to generate imaginary, apply their knowledge, and adhere to norms. In modern engineering education, the emphasis must be shifted to nurturing students' capacity to create imaginary and adhere to established norms, moving beyond traditional knowledge focused teaching. This shift represents an innovation direction in engineering education, with the aim of seamlessly integrating these three facets. Within each of these dimensions of engineering education, some aspects can be clearly articulated, while others remain ambiguous and challenging to convey. As digital education continues to advance, engineering education must increasingly prioritize these elusive elements. Achieving this necessitates the adoption of innovative teaching contents and methods to revolutionize the approach to engineering education.

Key words: engineering practice, engineering education, imaginary, knowledge, norms

INTRODUCTION

Engineering is distinct from science, and recent discussions in engineering education have highlighted the need to differentiate it from science education. Such a discourse underscores the practicality of engineering education, emphasizes the importance of nurturing students' hands-on and adaptive skills through educational innovation, including the integration of industry and education. People have come to realize that engineering education encompasses more than mere knowledge transfer; it involves the cultivation of practical abilities. Then, what does it mean to cultivate the ability of engineering talents? It should not just be the hands-on ability as what most people thought of.

Along with this, a significant shift in engineering education in recent years has been the increased emphasis on ethics education to enhance engineer students' ethical awareness and contribute to responsible engineering projects. But ethical norms do not function straightforward, and they are only one part of many normative requirements. Moreover, there is a growing recognition that engineering education should function as a transformative force serving society. In this respect, encouraging students to unleash their imaginations through engineering education is of utmost importance. As articulated by Albert Einstein, "Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulating progress, giving birth to evolution."[1] However, this view needs further consideration in the context of engineering education.

The purpose of this essay is to illustrate that engineering practice is a multifaceted endeavor, comprising the threefold root: imaginary, knowledge, and norm. Each fold has both visible and concealed aspects. While the visible aspects are easily comprehensible, the hidden aspects present challenges. The difficulty in engineering education lies in grappling with these elusive and intricate aspects, especially in the era of digitization. Therefore, it is imperative for engineering education to place greater

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emphasis on these less apparent aspects so as to foster virtuous engineers with sound abilities.

The threefold root of engineering practice: imaginary, knowledge and norms

Imaginary and engineering

Engineering is a forward-looking process that involves creating something from nothing. It's often said that scientists discover the world as it exists whereas engineers forge new worlds that do not yet exist. This raises questions: how does engineering emerge from nothingness? Since engineering is regarded as integration of technical and non-technical elements,[2] how does this integration occur? It is asserted that engineering is essential for human survival and development but where does its essence originate? To gain a deeper understanding of engineering practice and engineering education we must address these questions.

When discussing engineering as integration it implies a movement toward a specific goal. Such a goal comes from what is desirable which can be described with the concept of "imaginary". While this concept is often used in discussions of Chinese culture particularly in art history and literary criticism it remains unexplored in engineering philosophy and education studies. To comprehend and discuss engineering effectively we must introduce this concept. Imaginary encompass both explicit and implicit aspects often linked to individual or even collective unconsciousness.

Imaginary in Chinese denotes Yi plus Xiang (intention plus image), resembling a vision yet remaining more misty sometimes bordering on an unconscious state resulting from previous life experiences. An imaginary represents a concept infused with hope directed toward the future and intended to shape the future always carrying the potential for action.[3] As a result imaginary and imagination, while closely related, are not synonymous. For example, whereas we can imagine the solar system, this simply isn't imaginary. An imaginary includes desirable as well as visual aspect albeit less sharply defined. It reflects human's internal impulses and drive serving as a "vector" carrying the directionality of action. In contrast, imagination encompasses the direction of thought but doesn't inherently imply a behavioral disposition.

Engineering imaginary is a "vision" worth pursuing pointing toward the future rather than a mere image of a specific object. Imaginary guides engineering action constituting the foundation or cornerstone of engineering endeavors. The imaginary's genetic significance lies in its ability to shed light on existence. It points toward the future, generates a cohesive field, and transforms fragmented objects be (they materials, knowledge or humans) into engineering elements enabling the next phase of integration.

An engineering project originates in its imaginary, and without it the design and integration processes lack the very basis. Moreover, imaginary also plays a crucial role in persuasion in engineering projects. Engineering initiator must persuade others to join the project, and without a clear imaginary achieving this can prove challenging. Furthermore, many arguments about engineering projects rely on imaginary and engineering's evolution includes changes in these imaginaries.

Knowledge and engineering

The significance of knowledge in engineering is indisputable. This idea finds support in Francis Bacon's famous statement "knowledge is power." Knowledge functions as the core of the engineering practices "genome". Without knowledge there will be no engineering practices. Without new kind of knowledge there will be no new kind of engineering practices.

Engineering practices always involve the integration of diverse knowledge domains. This integration is driven by the inherently complex and multifaceted nature of engineering practices which requires the use of various forms of knowledge. Effective knowledge application necessitates its contextualization within the "engineering field." Such a process cannot be achieved through theoretical deduction in advance, for instance deriving aerodynamics from Newtonian mechanics, but rather unfolds in practical aeronautical engineering.[4] To amalgamate the diverse knowledge requires collaboration and interactions among professionals between professionals and stakeholders and among various stakeholders to become an integral part of the project.

Engineering practice consistently entails interdisciplinary collaboration. Knowledge in engineering practices encompasses expertise from various fields not only engineering knowledge but also scientific knowledge. Undoubtedly scientific knowledge holds a unique position and engineering endeavors cannot progress without the application of scientific principles. To integrate diverse elements in engineering practices relies on science which brings calculability and predictability to certain aspects of the endeavors in reducing the need for extensive experimentation. However, in discussions about the relationship between science and engineering, there's often a tendency to view science as superior and engineering as subordinate with engineering knowledge seen as derived from science. This perspective presents a misunderstanding. It's important to recognize that science doesn't dictate the engineering process: no single discipline governs how knowledge from other disciplines is applied creatively, and no single discipline prescribes the combination of various knowledge in the engineering design and implementation process. Such an integration depends more heavily on engineering imaginary and the corresponding design. It needs to point out in particular that tacit knowledge plays a more important role than the explicit knowledge in this process.[5]

Regarding the relationship between knowledge and imaginary, historical perspectives have oscillated between two extremes: one asserting that knowledge is truth while imaginary is illusion and the other conflating knowledge with social imaginary.[6] I propose a more nuanced perspective with three key facets: Firstly, knowledge and imaginary are not identical but share common ground and jointly influence human actions. Secondly, knowledge has its roots in imaginary and the generation of novel knowledge often sparks entirely new forms of imaginary. Thirdly, whereas knowledge is power for action, imaginary represents the direction of action imaginary defines the application context of knowledge guiding its utilization. With the intervention of imaginary, knowledge can be integrated into the creative process which invariably involves various "translations" in terms of Bruno Latour[7] rather than pure deduction.

Norms and engineering

Imaginary and knowledge alone are insufficient in engineering practice, and norms also play a pivotal role. The concept of engineering in Chinese is equivalent to work plus process, where "process" denotes normative and standard considerations. Hence engineering concepts inherently encompass norms which include both technical and social dimensions. Due to the inherent ambiguity in rules, rule-following often entails interpretation or translation. The manner in which engineers interpret and apply these rules in practice holds a unique significance as it involves translating relevant codes into constraints or parameters for specific design.

Of all norms technical norms are relatively clear and social norms (Law, regulation, ethics *etc.*) are more ambiguous. As one kind of social norms ethical codes are much more ambiguous broad and abstract lacking specific instructions for engineering practitioners. The ambiguity of ethical codes leads to the complexity of adhering to them. Firstly the true meaning of an ethical code can only be understood when put into practice. Secondly different individuals may interpret the same code differently. Thirdly people may follow the same code in different ways resulting in diverse outcomes.

To address the fuzziness of engineering ethical codes, it is necessary to contextualize them within engineering practice, provide specific explanations and emphasize their real-world significance. This process known as ethical interpretation involves specifying the meaning of ethical norms, related concepts and terms in order to apply them to specific situations.[8] Ethical interpretation reveals a creative approach to applying ethical codes. Engineers should focus on understanding the underlying principles of the code rather than just its formal expression. By utilizing ethical interpretations and relevant industry standards engineers can translate ethical guidelines into tangible constraints and technical parameters that can be integrated into artifacts, artificial processes or artificial systems. This entire process should be supported by legal frameworks customs and the prevailing social climate.

Engineering practices as synthesis of imaginary, knowledge and norms

Imaginary, knowledge and norms are individually significant and interconnected and constitute together as the root of engineering practice. This roughly aligns with Immanuel Kant's three fundamental questions in philosophy:[9] what can I know? What ought I to do? And what may I hope? In engineering practice similar questions arise: what we want to undertake (related to imaginary), which capability do we have for doing so (related to knowledge), and how should we proceed (related to norms).

Engineering practice relies on the combination of imaginary, knowledge and norms to drive the engineering process forward. An engineering project is intrinsically linked to imaginary signifying the possible futures and generating a working field. Knowledge serves as the foundation for action and a source of power. Norms encompass rules and regulations acting as navigational tools which ensure adherence to the desired course of action. It is integration of these three elements that enables successful project completion. In this process there is an interaction between matrixes: (imaginary, knowledge, norms) as the intangible matrix acts upon the tangible matrix (actors, objects, texts), generating new matrix (new actors, new objects, new texts), and even another new matrix (new imaginary, new knowledge, new norms).

This is a process of creation of the artificial in which engineering tradition provides a foundation. The tradition can be regarded as the combination of all kinds of imaginary, knowledge and norms within a specific field. Science can contribute to the renewal of this tradition by discovering new phenomena and introducing fresh structure-function relationships. Similarly art facilitates the renewal by introducing new imaginary and novel life possibilities. In this way engineering innovation becomes possible involving the generation of new imaginary, knowledge and norms.

In short, engineering practice entails a journey from abstraction to reality, from the virtual to the tangible and from the unseen to the visible. Within this journey imaginary, knowledge and norms represent structural elements. All these three encompass ineffable aspects which collectively constituting the tacit dimension of human action not just tacit knowledge. These ineffable aspects are intertwined serving as the foundational basis of our actions and the essence of engineering practice.

Triple essentials in engineering education: imaginary, knowledge and norms

The above analysis sheds new light on engineering education. Since imaginary, knowledge and norms are the threefold root of engineering practices in order to achieve "engineering itself", *i.e.*, ideal engineering, practitioners must possess three essential abilities: the capacity for imaginary generation, knowledge application and norms interpretation. The objective of engineering education should nurture these abilities of students in order to help shape the virtue of engineering talents. Only those possessing these qualities can be recognized as virtuous engineers.[10] To cultivate engineering talents with this expertise educators must first acknowledge that engineering practice has threefold root corresponding to the three abilities crucial for engineers. This perspective provides education with a clear objective moving beyond the focus of the single dichotomy between knowledge and practical skill.

While explicit aspects of imaginary, knowledge and norms are readily comprehensible, the challenge in engineering education lies in addressing the elusive tacit components of them especially in an era dominated by network, digital technology and artificial intelligence. Therefore the focus of engineering education should shift towards these tacit aspects, a direction that is undoubtedly imperative. The basic principle is "learning doing by doing": To master knowledge by knowledge applicating, to gain imaginary by imaginary generating and to learn norm interpretation by norm interpreting. This is actually an iterative learning process in engineering education. In so doing the face-to-face guidance of university educators and engineering professionals is indispensable for cultivating tacit skills of generating imaginary applicating knowledge and interpreting norms although "online education" and "virtual laboratories" are proliferating and "digital teachers" driven by generating artificial intelligence is altering the landscape of knowledge dissemination.

Building upon this foundation it needs to reconsider the teaching contents and methods to facilitate the integration of these three essentials.

Science education must not be underestimated

In considering that engineering practice is an interdisciplinary undertaking engineering talents must have an interdisciplinary knowledge base, remain attuned to other professional and scientific domains and be prepared to adapt to meet diverse external challenges. In view of the fact that engineering practice cannot be separated from the support of science, and that engineering innovation depends heavily on the input of new structure-function relations from scientific discoveries, science education is a necessary part in engineering education and the two are not mutually exclusive relations. Of course science education should serve for the ternary abilities to generate imaginary, applicate knowledge and interpret norms.

Arts-based education should be strengthened

The ability to generate imaginary refers to the capacity to envision future possibilities. Imaginary is the starting point of the engineering process and engineering design involves transforming vague imaginary into precise blueprints. The connection between engineering and art is essential as art plays a crucial role in nurturing this ability to drive engineering innovation. By stimulating emotions and imagination art can enhance the imaginary skills of engineering talents. Additionally art can serve as a significant bridge for the influence of science on engineering. Recognizing the intrinsic relationship between art and engineering it is important to strengthen the art education of engineering students. In this regard science fiction teaching and writing practices should be more extensively utilized to enhance students' ability to generate imaginary.

Normative education should focus on interpretation exercises

Considering that norms are generally broad and abstract no specific actions can be prescribed simply teaching engineering ethics principles to students without teaching them how to apply those principles in reality may lead to the problem of "learning one set and doing another." This can result in a disconnect between normative codes and actual engineering practice. Instructors should therefore not only communicate normative provisions but also educate students on how to interpret and apply these norms. The ability to interpret norms and transform them into technical parameters is a vital aspect of engineering talent competence.

Case-based teaching should be reconstructed

Although case-based teaching is commonly employed in engineering education its purpose is often misunderstood with many focusing solely on instructing students within the framework of knowledge and practical skills. However competence is not simply an extension of knowledge achieved through practice involving gain of tacit knowledge. The tacit dimension actually encompasses more than just knowledge it also includes the intangible abilities for imaginative construction and norm interpretation. In case teaching it is crucial to foster critical thinking, engage in critical dialogue and explore alternative possibilities through comparative analysis. This approach enables case teaching to simultaneously serve as a platform for imaginative education, knowledge acquisition and understanding of norms.

Project-based teaching should be the focus

While case teaching reflects the history of engineering, project-based teaching reflects the contemporary practice of engineering. By engaging in small-scale projects students have the opportunity to experience the entire process from conception to completion and engage with the dimensions of imaginary knowledge and norms simultaneously. In conducting projects comprehensive knowledge across multiple disciplines is essential, and students are required to construct their own imaginative images and interpret norms in a nuanced manner. As a result, students will inevitably encounter various challenges which provide an ideal environment for them to understand in-depth the threefold root of engineering, grasp its fundamental principles and develop their own threefold skill. Thus rather than relying solely on writing academic papers the main method of assessment for engineering students should be engaging in practical engineering projects.

The involvement of industrial engineers matters

Case-based teaching and project-based teaching both benefit from the involvement of industrial engineers. While university teachers excel at imparting knowledge to students, industrial engineers bring a fresh perspective that enhances students' imaginative and interpretive abilities. By integrating industry and education the quality of engineering education can be significantly enhanced in fostering the development of students' skills in all three dimensions. This approach has the potential to transform the current engineering education framework by shifting its focus.

In short, recognizing the threefold root of engineering practice, educators should strive to develop students' abilities for imaginary generation, knowledge application and norm interpretation. By adopting tailored teaching methods across these dimensions educators can nurture virtuous engineers who will excel in their field.

CONCLUSION

Engineering practice has intangible threefold root: imaginary, knowledge and norms. Practitioners must possess the abilities to generate imaginary, apply knowledge and adhere to norms. Each of these has both explicit and ineffable components. The ineffable aspects of these are interconnected and inseparable. The engineering activities require individuals or organizations equipped with a strong capacity of imaginary, a high level of knowledge and a strong sense of normativity.

Engineering education should extend beyond imparting engineering knowledge including tacit knowledge and put greater emphasis on cultivating students' capacity for imaginary generating and normative interpreting. In so doing their engineering wisdom would be gradually grow up, including the ability to conceive new possibilities based on fragments of knowledge, devise plans to transition from the current state to these potential scenarios, and execute these plans while achieving consensus. Only individuals possessing these competencies can they excel in engineering practices. This shift is at the core of innovation in engineering education aiming to comprehensively integrate these three essentials. Since each of them has both expressible and enigmatic facets, as digital education advances engineering education must increasingly prioritize these obscure elements. To achieve this new educational contents and methods are required to help transform the engineering education paradigm.

Fundamentally speaking, engineering education is about teaching students to understand engineering tradition which can be regarded as a combination of specific types of imaginary, knowledge and norms. Such tradition is embodied in textbooks, word-of-mouth stories, mentoring rhetoric and various engineering regulations. In the face of problems engineers can be inspired by it form an imaginary of problem-solving, contextualize knowledge, and interpret ethical norms in order to adapt to problem-solving. It is always the most effective way to learn from past engineering cases and those around you. In this sense engineering education is about handing engineering traditions to students.

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Conflict of Interest

Wang DZ is an Editorial Board Member of the journal. The article was subject to the journal's standard procedures.

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