Consolidating engineering design and design thinking frameworks for teaching design to engineering students at liberal arts universities

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Consolidating engineering design and design thinking frameworks for teaching design to engineering students at liberal arts universities

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Abstract: In the post-industrial revolution era, after a prolonged period of ever-increasing emphasis on specialism in undergraduate engineering education, in recent decades there has been a shift towards promoting generalism and the development of trans-disciplinary problem-solving skills. Such reprioritizations of learning outcomes have been the most explicit and deliberate at liberal arts universities. A consequence of this reimagining has been the co-opting of the design process-based problem-solving framework, traditionally considered to be an engineering or architecture instrument, by other disciplines like management, arts, humanities and social sciences. The advent of frameworks like 'human-centered design,' or 'design thinking' has formalized the discipline-agnostic teaching and application of design, and has led to the creation of multiple sets of vocabularies and implementation schemes despite all having recursive iterative and adaptive features at their core, emphasizing similar values, and calling upon overlapping cognitive competencies.

This paper compares the engineering design process to popular design thinking methods in an effort to consolidate the two by highlighting similarities and differences between them. The comparison is based on a review of the literature and pedagogical experiences of faculty teaching both processes to engineering students at a liberal arts university. The traditional domains of application of the two approaches and modalities of various stages of the processes are analyzed to understand the spirit of each framework and then comment on their implementation attributes like the relative emphasis on quality vs efficiency, level of iteration, mindset cultivation, and innovation. Variations in these implementation attributes, and not underlying cognitive structures, are hypothesized to be the source of differences in the two frameworks. A mapping across the two is presented, and some recommendations about their teaching are shared. It is hoped that design educators can use learnings from the comparative study in course design and teaching to enable engineering students to: (i) understand general principles of design-based problem-solving and develop a designer's mindset, (ii) link problem-solving techniques taught in engineering and non-engineering courses/contexts, and (iii) develop necessary skill and vocabulary sets to interact with non-engineers trained in various forms of the design framework.

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1. Introduction

The last decade has seen a rise in the inclusion of "Human-Centered Design" or "Design Thinking" courses in the engineering curriculum. This is owing to the success of design thinking as an innovation model adopted by businesses worldwide [1] and calls by educators for its inclusion in the curriculum, going as far as calling it the new liberal arts [2]. "Design Thinking (***DT***)" here refers to the problem-solving framework popularized during the 2000s by institutes like the *Hasso Plattner Institut* [3] in Germany, the Hasso Plattner Institute of Design (*d.School)* [4] at Stanford University, and design consultancy firms like *IDEO* [5].

The inclusion of design in the engineering curriculum is not new, and Engineering Design (***ED***) as a problem-solving framework has been formally taught to engineering students since the latter half of the last century, either as engineering design or a discipline-specific version of it, e.g., mechanical engineering design, chemical engineering design. The inclusion of design as a core graduate attribute in engineering accreditation requirements [6] and the prevalence of design courses (cornerstone, capstone, industry-sponsored projects) in engineering curricula worldwide is a testament to the importance afforded to it by engineering educators. This is natural, as design has always been the distinguishing feature of engineering practice [7, 8]. Then, why is there a need for these courses on DT? It should be noted here that the term "Design Thinking" will only refer to formalized DT frameworks, e.g. [9, 10, 11], in this paper, and not to the cognitive process that designers engage in while implementing a design framework[3], work on which has been going on since the 1970s by engineers, cognitive psychologists, and educators interested in the pedagogy and psychology of design, e.g. [7, 12, 13, 14].

It is well-accepted that engineers should be able to design effective solutions to meet social needs [15]. Traditionally, the engineer has been satisfying these social needs in the realm of industrially manufactured products. However, the nature of problems that engineers are being required to solve today have evolved to the realm of complex systems, at the nexus of different disciplines and interconnected with other systems. Humans are increasingly part of these complex systems, and the behaviors of both the systems and involved humans are influenced by each other. The terrain of innovation has expanded with the shift of economies from industrial manufacturing to knowledge and service, resulting in expected solutions of the design process to also evolve to include services, interactions, entertainments, and processes. The problems are further complexified by their strong connections to social, economic, and environmental systems, perhaps resulting in wicked problems[4]. If engineers are to continue to make impactful and innovative contributions in solving these real-world problems then they require an enhanced toolkit.

Design researchers have made various attempts at devising new tools to address these new kinds of problems, e.g., transdisciplinary design, design thinking (DT). The goal of this paper is to examine the similarities and differences between DT and ED frameworks to explore questions related to the inclusion of DT in the engineering curriculum. Should both the frameworks be taught to engineering students? If both the frameworks are to be taught, how

[3] e.g. "The pattern of decomposing concepts into its sub-elements and extracting a single element has been shown to be crucial to effective *design thinking* and reasoning." [26], "Engineers must organize their design processes to communicate their *design thinking* to their design partners." [13]

[4] Wicked problems are a "class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing." Rittel quoted in [10].

can this be done harmoniously and efficiently in an integrated and synergistic fashion so as not to confuse students? What vocabulary should be used in teaching design – DT's or ED's? How do the two frameworks map to each other? The primary motivation behind this paper has been the authors' desire to establish cognitive consonance between the two design frameworks, currently being taught to Electrical and Computer Engineering students at a recently formed liberal arts university in Pakistan, Habib University.

Towards this end, the paper first sets the ground for comparing the two frameworks by formally defining them in the next section, after which the salient differences between the two are identified across various dimensions. At the end, some recommendations are presented to guide congruent teaching of the two frameworks to engineering students.

2. Definitions

2.1. Engineering Design

A few formal definitions of design obtained from various engineering design textbooks are presented below:

- "Engineering design is a systematic, intelligent process in which engineers generate, evaluate, and specify solutions for devices, systems, or processes whose form(s) and function(s) achieve clients' objectives and users' needs while satisfying a specified set of constraints." [16]
- "Engineering design is the process of applying the various techniques and scientific principles for the purpose of defining a device, a process or a system in sufficient detail to permit its realization." [17]
- "To design is either to formulate a plan for the satisfaction of a specified need or to solve a specific problem. If the plan results in the creation of something having a physical reality, then the product must be functional, safe, reliable, competitive, usable, manufacturable, and marketable." [18]
- "Design establishes and defines solutions to and pertinent structures for problems not solved before, or new solutions to problems which have previously been solved in a different way." [19]

Each of these definitions is accompanied by a process model describing various stages of the design process. Engineering design generally begins with a need and ends with communication of the final design. Process models, describing the intervening stages, range from being "descriptive", describing the sequence of activities that occur in designing, to "prescriptive", proposing appropriate activities for each stage [20]. An examination of models from engineering textbooks [16, 17, 18, 19] reveals that they possess structural similarities and go through similar stages, complete with numerous internal feedback loops. A consolidated ED model distilled from the reviewed models is used herein to aid the following comparative discussion. The consolidated model is shown in Figure 1, and aligns with the model proposed by French [21]. More systematic and rigorous comparisons of various ED frameworks can be found in the literature [22, 23, 24].

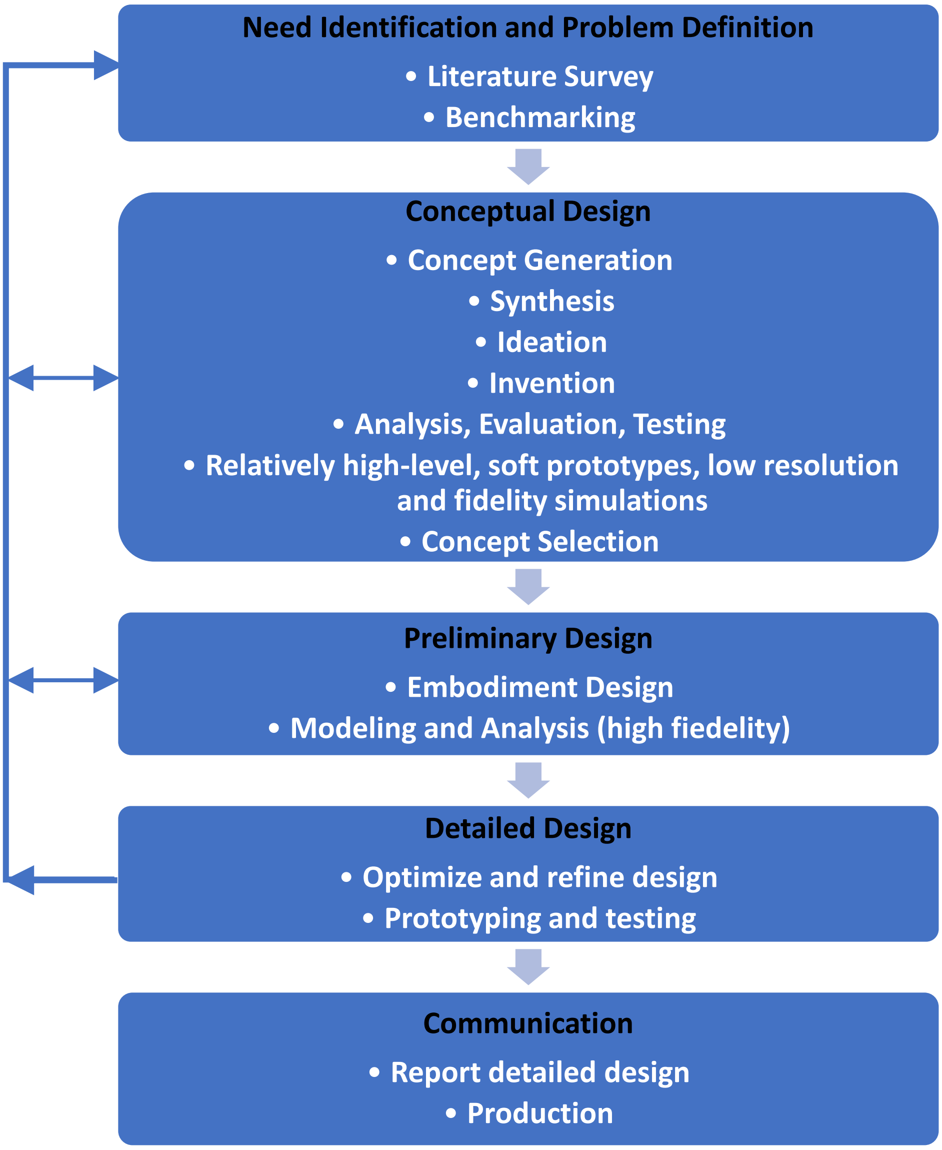

Figure 1: A consolidated representation of the engineering design process with important descriptors listed.

A description of each stage is provided below:

1. ***Need identification and problem definition:*** The problem to be solved is "identified", a "need analysis" exercise is carried out by discussing the problem with the principal stakeholders (clients and users) and carrying out background research to better understand the problem and the "state of the art" (benchmarking). Next, the design requirements are identified and stated in engineering terms. This entails identifying design objectives, establishing design constraints and functions, and prescribing performance specifications; all in general, solution-independent terms.

2. ***Conceptual design:*** Design requirements are used to conceptualize various design concepts / alternatives (concept generation) that are then evaluated using metrics and tests, and the "objectively best" solution(s) is / are selected for further consideration

(concept selection). The tests are relatively low fidelity, resolution, and cost; and are used primarily for comparison purposes.

3. ***Preliminary or Embodiment design**:* The selected concept(s) is / are ascribed with specific details, e.g. about its architecture, configuration, and dimensions, based on results from high fidelity analyses and modeling exercises. A final concept selection is made.
4. ***Detailed design:*** All missing information is added to the embodiment design and, within the narrowed design space, the design is optimized, and a prototype is produced.
5. ***Communication:*** Required communication artifacts (e.g., CAD models, engineering drawings, reports, presentations) are generated to convey important information about the design to relevant interfaces - sponsors, manufacturers, clients, etc.

2.2. Design Thinking

It is difficult to precisely define design thinking as, unlike ED, it is simultaneously a mindset as well as a problem-solving process. Helpful discussions on these definitional challenges can be found in Barsalou [25] and Dorst [26]. A few utilitarian definitions of design thinking obtained from DT toolkits are presented below to facilitate the comparative discussion that follows.

- "Design thinking is a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity." [1]
- "Design thinking is a system used to creatively solve problems through a range of analysis and synthesis techniques. It aims to build a holistic understanding of the end-user and challenge assumptions that are being made in any given scenario." [27]
- "Design thinking is a problem-solving approach that is human-centered, possibility-driven, option-focused, and iterative in nature (and solves problems by asking) four questions – what is? what if? what wows? and what works?" [11]
- "Design thinking is a non-linear, iterative process that teams use to understand users, challenge assumptions, redefine problems and create innovative solutions to prototype and test." [28]
- Design thinking is a mindset that is human-centered, collaborative, optimistic, and experimental in nature. It is implemented via a design process comprising five stages (discovery, interpretation, ideation, experimentation, and evolution) to generate relevant solutions and create a positive impact. adapted from [9]

Flow diagrams accompanying these DT definitions had similar structures and a consolidated diagram with commonly used descriptors for each step is presented in Figure 2.

1. ***Empathize:*** DT begins with understanding people, and trying to focus on a definable problem that this group of people has. This entails carrying out observational research

by foregoing assumptions and opening oneself to creative possibilities. The human-centered approach to design thinking places the needs, desires, and experiences of people at the forefront of the design process [1]. By adopting a human-centered approach to design thinking, designers can create products and services that are more relevant, usable, and meaningful to people, and ultimately, more successful in the marketplace.

2. ***Define:*** The insights generated and information gathered in step 1 are "downloaded as a team," compiled, analyzed, and used to: (i) frame the design challenge in the form of problem statements, (ii) build a collective consciousness, and (iii) establish design principles (guidelines) for the problem at hand.

3. ***Ideate:*** Next, ideas are generated and solution opportunities are identified based on the information collected during the preceding two steps. Various brainstorming, pattern recognition, clustering, and visualization approaches are used for this. The principal stakeholders (the users) are engaged in the ideation activities.

4. ***Prototype:*** Experiments are carried out to test the performance of generated solutions through the use of inexpensive, low-resolution prototypes; and the best performing design solution(s) is / are selected and refined based on experimental learnings. According to *Brown* [1], "Prototypes should command only as much time, effort, and investment as are needed to generate useful feedback and evolve an idea."

5. ***Test:*** The winning design from stage-4 after being refined is rigorously tested under real-world settings, and the learnings from such high-resolutions tests are used to refine it further to maximize its impact. This can be thought of as a pilot or a beta version of the solution, even though the term "learning launches" is preferable according to *Liedtka & Ogilvie* [11] because of the implicit connotations of learning and iterating.

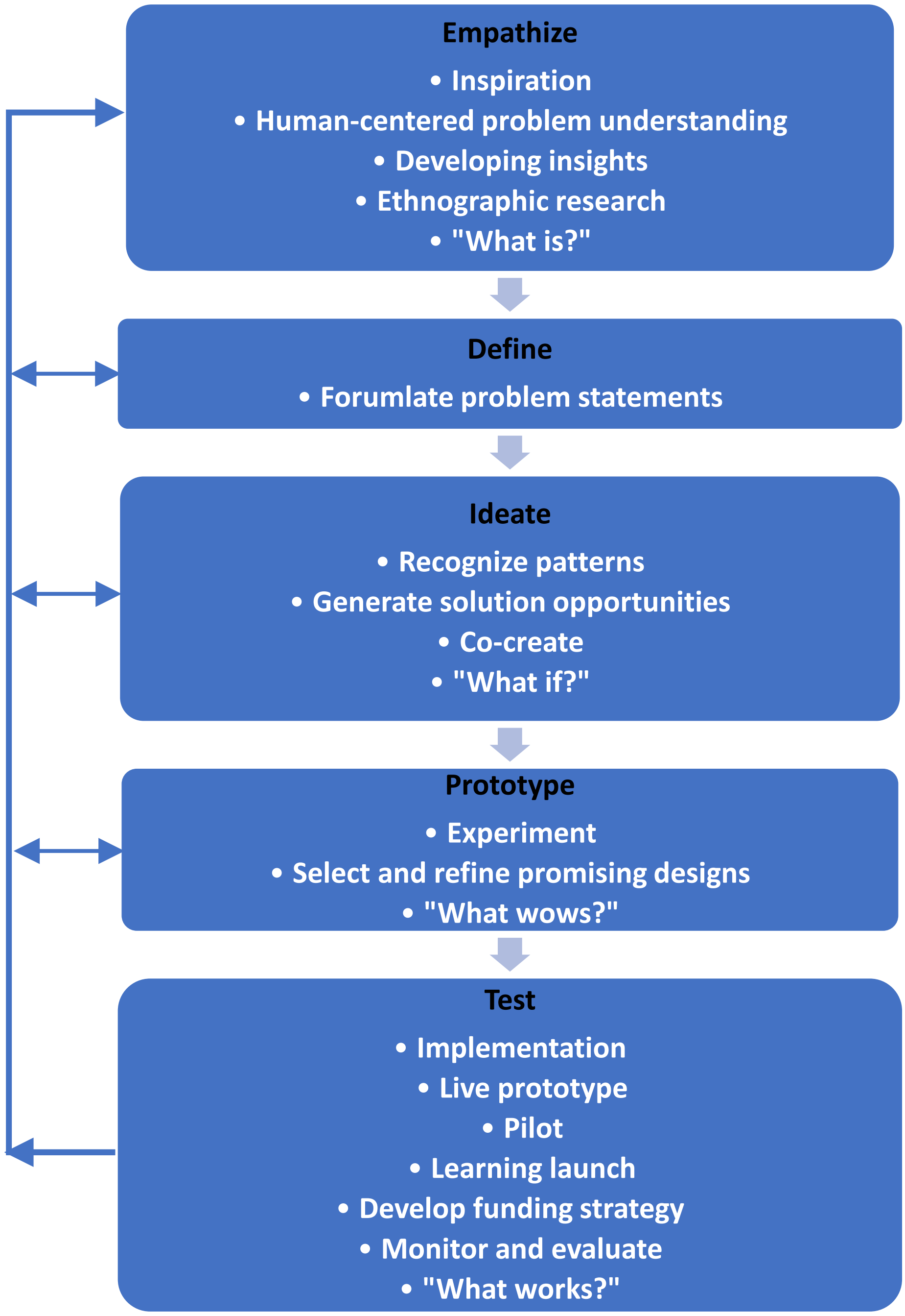

Figure 2: A consolidated representation of the major steps in design thinking-based problem-solving.

3. Comparison of "design thinking" with "engineering design"

This section provides a comparison between the frameworks of "Design Thinking" and "Engineering Design". The analysis is based on the authors' interpretations of available literature on the two frameworks and the personal experiences of the authors in teaching courses on these topics at their university. These courses include "Engineering Workshop", which is a first-year mandatory course on Engineering Design for engineering students; "Design your University Experience", which is the first course on Design Thinking at the university; "Engineering Design and Innovation", a junior-level course that covers the practices of Engineering Design, Design Thinking, and Systems Thinking; and "Computer-Aided Engineering", an elective course for juniors and seniors.

In general, it is not unexpected that both design frameworks have a comparable approach and possess features typically present in all design processes. Some of these similarities are:

- Both are iterative, adaptive, and collaborative processes that help solve ill-defined and open-ended problems that are not amenable to being routinized or solved algorithmically (aka “puzzles”). The iterative and nonlinear nature of both design methodologies is reflected in the existent feedback loops. This iterative nature can also be viewed as coevolution of the problem space with the solution space. That is, as designers search for solutions, they may gain a better understanding of the problem space, which can lead to more effective solutions.
- Both aspire towards the synthesis of an acceptable (not optimal) solution in a reasonable amount of time by providing support structures that promote innovation in a systematic way; and, in so doing, they remove “natural creativity” or “genius” as a prerequisite for innovation and expand the tent of innovators to include anyone who follows the design process. DT calls this mindset creative confidence.
- Both utilize divergent and convergent thinking to, respectively, generate ideas, and select and refine the best ones. Convergent thinking is defined as attempt to converge on and reveal ‘facts’ that are to be verifiable [14], e.g., convergence to a problem definition reveals the ‘truth’ about the desires of stakeholders. Divergent thinking, on the other hand, is a designer’s attempt to diverge from the facts to possibilities that can be created from them, e.g., brainstorming possible solutions to a defined problem. The “best” is determined in both, either directly or indirectly, by comparison with the end-user’s needs. In-built adaptive structures try to keep the solution being evolved in-sync with the user’s needs. Moreover, both promote values like deferred judgment and least commitment during divergent thinking stages.
- Both subscribe to the “fail early to succeed sooner” rule.

However, there are nuanced differences between DT and ED in terms of their implementation and the emphasis placed on various aspects of the problem-solving process. Often, these differences are not immediately apparent and can be hidden behind differing terminology. Such differences – even if minor and mostly semantic – can be a source of confusion for engineering instructors and students alike. It should be noted that this comparison is based solely on the prescribed emphasis each method places on different stages of the design process, and that an experienced practitioner of either method may have identified their own levels of emphasis to be placed on each stage with time. The differences between the two design frameworks across different dimensions are highlighted below.

3.1. Mapping

The authors have attempted to identify the counterpart of each stage of the DT process (Figure 2) in the ED process (Figure 1), as outlined in Figure 3. The identification is based on matching the objectives of each design stage, as defined above. Such mapping across DT and ED frameworks might help avoid confusion stemming from differences in the vocabularies of design by identifying counterparts for each stage. Structural similarities between the two processes are obvious in Figure 3, and even though most of the labels used for the various design stages are different across the two frameworks, almost all the steps map to an equivalent step in the other framework. In the authors opinion, the one-to-many and many-to-one mappings appearing in Figure 3 are a reflection of the varying emphasis placed on the different stages in the two frameworks, e.g., the attention paid to empathy as an important step for problem definition in DT, the specific highlighting of prototyping in DT, or the number of stages devoted to the systematic addition of details in ED. This is only a first attempt at mapping and most likely does not capture all the couplings that exist between ED and DT.

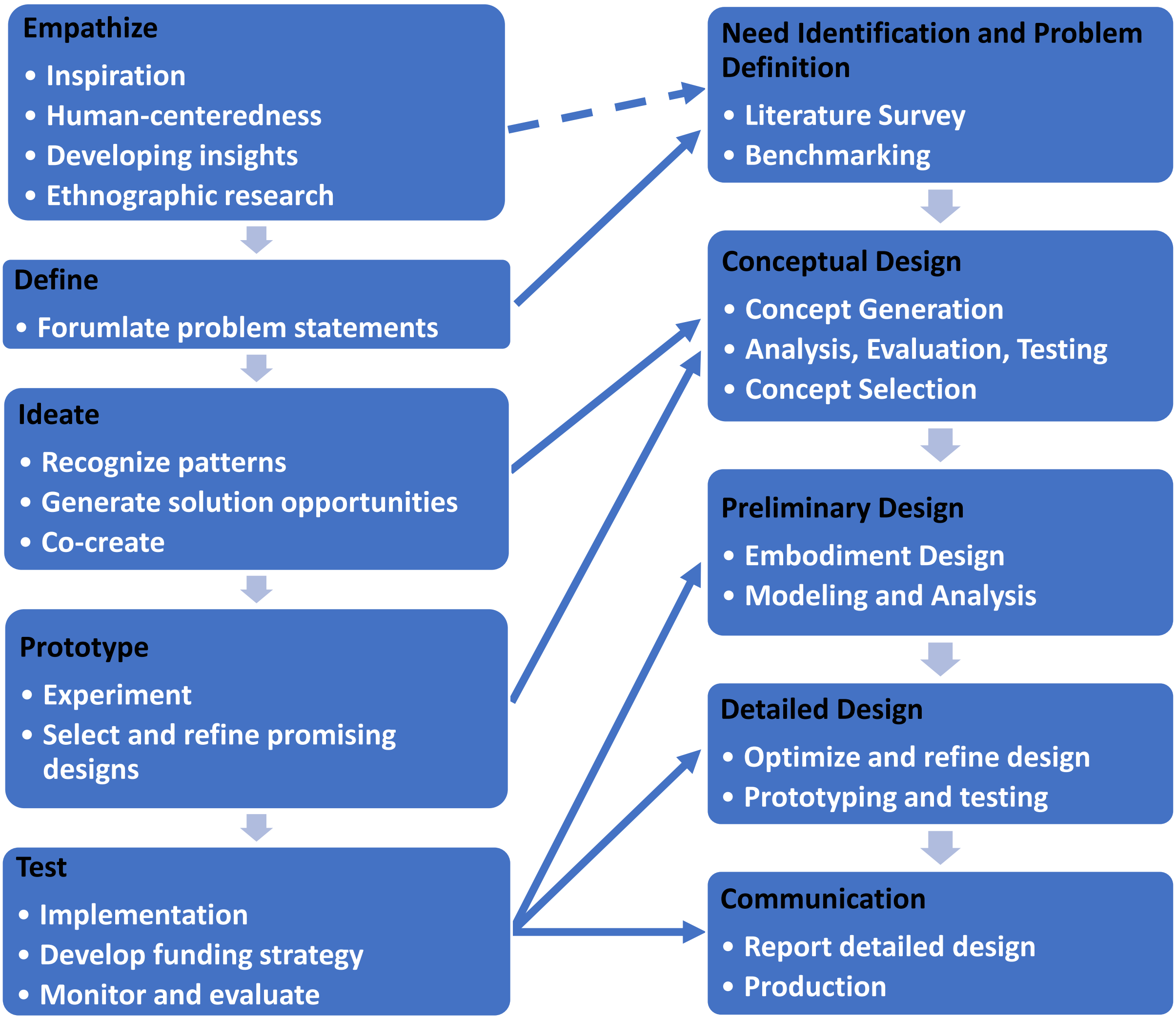

Figure 3: Mapping of the design thinking framework (left) to the engineering design framework (right). Dashed line signifies weak mapping

3.2. Nature of problems being addressed

Even though both the frameworks study "puzzles", DT, which is decoupled from any specific field or specialization, targets a broader category of puzzles and appears to excel at looking for solutions to multi-faceted socio-economic problems with complex interdependencies that have direct implications on people's quality of life [36, 37, 38, 39]. This claim is being made on the basis of the human-centered nature of DT. In comparison, ED is *usually* used to solve engineering problems that are relatively tame in nature when compared to the subjects of DT.

Moreover, the solution to these problems is usually a tangible product (widget, artifact, artifice, device, prototype), however, the solution could also be a process or a system. The outputs of DT problems can be much more varied in nature, e.g., artifacts, processes, services, experiences, policies, business plans. The foregoing claims are generalizations based on the authors' experiences and are intended to convey differences only in the typical applications of the two frameworks. As an example, in one of the courses taught by one of the authors, students have successfully produced a document reader using ED, and in another course taught by the other author, students have discovered and addressed problems related to mobility in the city using DT. It can be rationally argued that ED also pursues complex socio-economic, wicked problems when it is used to solve problems affecting "complex engineering systems[5]" by employing "systems thinking" [14].

3.3. Emphasis on problem definition and empathy in DT

As mentioned above, DT prides itself on being human-centered [29, 30, 40]. Because of this human-centered architecture, a lot of emphasis is placed on understanding the problem directly from those facing it (the users) as a part of the empathy / inspiration stage. Designers immerse themselves in the situations they are trying to solve and understand the problem from the users' perspective through ethnographic methods.

In contrast, ED can be viewed as technology-centered or business-centered. Problems are usually defined in ED by design engineers interpreting objectives, constraints, and functional requirements based on the problem description of an intermediary – the client – who speaks on behalf of the user, oftentimes based on their assessment of the user's needs. As a consequence of this indirect communication, the need identification and problem definition stage is not given as much time and attention as it deserves. According to *Norton* [17], engineers rush through this stage to get to the ideation and invention steps.

Moreover, once the problem has been defined in engineering terms, these specifications serve as a benchmark against which the final design's performance is gauged. Therefore, any lacuna in defining the problem will propagate throughout the solution development process and will result in a poor-quality solution. However, in DT the "Problem Definition" stage is placed in the middle of the design process, allowing for "the reframe" [30]. It is this opportunity to reframe the problem that ensures that a design thinker is solving the most important problem for the users or people they're trying to help.

This distancing between the engineering designer and the people for whom we're designing in ED, possibly desirable on the designer's part, has been termed as "social captivity of engineering" by Goldman, as indicated in [41]. With rapid innovations in AI, Robotics, Biomedical Engineering, carrying the potential to radically alter socio-politico-economic systems, isn't it wise to ask "Who is this solution serving?"

[5] A class of systems characterized by a high degree of technical complexity, social intricacy, and elaborate processes, aimed at fulfilling important functions of the society. [13]

3.4. Difference in the definitions of "Prototype" in the two frameworks

In ED, a prototype refers to the first full-scale and functional physical realization of a new design that is tested under real-world conditions. This stage in solution development is categorized as "Technology Readiness Level (TRL) 6" by NASA [42]. In DT jargon, however, "prototype" is similar to the "model" of ED, whereby it is used to quickly and inexpensively test a concept. Any setup possessing sufficient level of detail to evoke a response from the audience that can be used for design improvements is considered a prototype in DT. This is TRL 3 in NASA's stages of development. While most ED models are simulation based, DT prototypes can be varied in nature, ranging from artifacts to scenarios and events, but generally they do involve the use of a physical realization of the design. Often these prototypes involve play and making, both of which are strongly encouraged in DT. The interested reader is referred to *Jensen et al.* [31] that presents an excellent discussion on the varied use of the term "prototype" in different engineering disciplines.

3.5. Quality of solutions and efficiency of the design process

"Effectiveness" in design refers to the ability of a design to achieve its intended goals and objectives. Effectiveness is important because it ensures that the design is solving the right problem and achieving the desired results. "Efficiency" in design, on the other hand, refers to the ability of a design to accomplish its goals in a timely and effective manner, with minimal waste of time, effort, or resources. Finally, "Quality" of a design is the degree to which it meets established standards and criteria, which are derived from the objectives of the design but are amenable to tests in the designer's workspace.

ED has a natural focus on efficiency, while DT prioritizes effectiveness. The emphasis on efficiency in ED might be necessitated by: (i) the kind of (relatively focused and narrow in scope) problems that are its typical subjects, and (ii) the need to deliver engineering solutions in a reasonable amount of time. An overemphasis on efficiency can lead to a lack of creativity and innovation. When designers are focused on meeting a specific set of quality criteria, they may be averse to risk taking that could lead to innovative designs. Designers may also miss out on considering the social, environmental, cultural, and ethical implications of their design. In contrast, effectiveness is prioritized in DT by periodically testing prototypes with the users and other relevant stakeholders at various stages of the design process. Users can even be engaged directly in the ideation processes and treated as "co-designers" / "co-creators" in the generation of design solutions.

Therefore, it can be argued that engineering design is more efficient than design thinking, while design thinking is more effective.

3.6. Innovation and impact

Both frameworks mandate spending time on reflection and disagreement, and encourage the designer to embrace ambiguity that accompanies the diverging stages as doing so leads to innovative solutions [11, 14, 32]. However, it is being contended herein that DT leads to more innovative solutions. This statement is supported by two key observations: Firstly, DT methods, which prioritize divergent thinking, facilitate rapid expansion of both problem and solution spaces. Secondly, DT's human-centered approach places human desirability as a mandatory prerequisite for developing innovative and sustainable solutions. In addition to human desirability, two other prerequisites for developing innovative and sustainable solutions are technological feasibility and economic viability. However, while ergonomics and engineering economics are often included in engineering design textbooks, e.g., [19, 33], technological feasibility tends to be the most emphasized aspect in ED. This ultra-focused emphasis on technical feasibility has been shown to diminish creativity[6] over the course of a four-year engineering education [34]. Given this evidence, Design Thinking (DT) can be recognized as a potential approach for generating more innovative, disruptive, and impactful solutions.

3.7. Level of iteration

Based on the comparison of ED's and DT's structures and the way their application is discussed in respective literature, the general impression was developed that ED has a less iterative and a more serial flow compared to DT. The perceived serial flow in ED can be attributed to: (i) over-emphasis of technical feasibility in ED during the concept generation and selection stages, and human-centeredness of DT that maintains regular communication with the stakeholders because of which feedback on design concepts is regularly harvested to affect design changes, and (ii) relatively greater encouragement in DT to embrace the ambiguity of the problem-solving process by "living the questions"[7] and leveraging it to think of innovative solutions because "the most fundamental natural law of innovation is that the only certainty is uncertainty." [11]. Indirect evidence of this conclusion can also be obtained from the choice by *Dym et al.* [16] not to show feedback arrows in their ED flow diagram as "it is important not to be overly distracted by these adaptive characteristics when learning about doing design for the first time."

The foregoing comparison can also be stated in terms of the frequency of converging and diverging stages in the frameworks. Both ED and DT have an initial diverging stage when the problem is understood (need-identification / empathy / discovery / inspiration), followed by a converging stage when the design requirements are established, and the problem is defined. Next comes another diverging stage when design concepts are generated (ideation), which tapers off during the concept selection and refinement stages (preliminary design / detailed design / prototype) and terminates with the unveiling of the final solution and supporting artifacts. An illustration of these structures in DT, adapted from a DT toolkit [9], is shown in Figure 4. In such a process representation, the higher iterative-ness of DT would appear as a series of converging and diverging convulsions with diminishing amplitudes that eventually converge, whereas, in ED, secondary perturbations would be fewer, and the process would converge earlier.

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[6] Creativity is defined as "production of novel useful products" or "ideas that are both original and feasible."

[7] "Design thinking approaches force you to really live in this unclear, sometimes very muddy place to get a better understanding. This ends up producing a much better understanding of the problem and the challenges that you're trying to solve." *Barry MacDevitt (Design Dublin)*

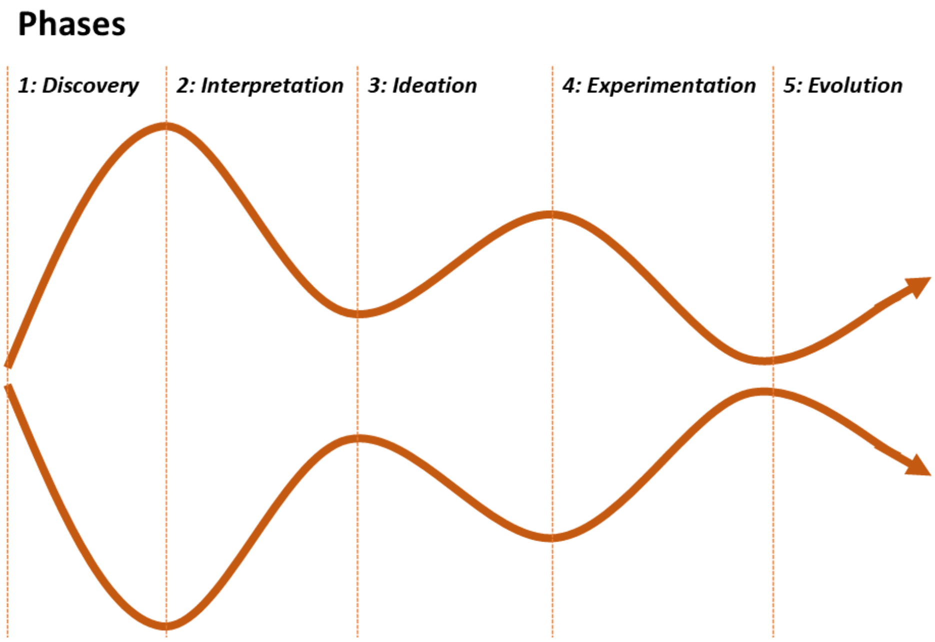

Figure 4: Converging and diverging stages of the DT process. Adapted from [9]

3.8. Design Methods

The design methods adopted for ED typically lean towards being precise, analytical, and algorithmic. The methods could have their roots in decision theory. The representation of ED requirements using measurable quantities as well as the typical expression of objectives in terms of cost allows for the use of such analytical tools. On the other hand, the human-centered nature of DT and the need for frequent feedback from users requires the adoption of qualitative research methods.

3.9. Mindset

DT focuses on the development of the "right" mindset that is conducive to generating high-quality, and innovative solutions. The two most important tenets of this mindset are optimism and team efforts. DT preaches the belief that design solutions are out there waiting to be found in the design space, and by continuous engagement with the stakeholders an acceptable solution can be found. Compared to this, only passive references to the designer's mindset were made in the reviewed ED literature. Resultantly, where DT focuses on design opportunities through the designer's mindset, ED focuses more on the constraints and design limits.

3.10. Prescriptive model for DT?

The DT framework was found to be less prescriptive (still prescriptive though, not descriptive) than the ED process even though standardized design devices like mind mapping, collages, frameworks, storyboards are extensively used in DT toolkits. However, developing the right problem-solving mindset lies at the core of DT and the devices are mere tools that utilize the DT mindset in a streamlined manner, whereas, in ED, there are standard design artifacts (e.g., house of quality, morphological charts) that are considered important for problem-solving. They serve as checklists and provide instructions on the implementation of the framework.

3.11. Expansion of role of designer in DT

The DT process expands the role of the designer at both ends of the design process. At the beginning, it includes activities such as user research and gathering insight, which would typically be part of the product planning staged (pre-design) on the ED side. Similarly, it allows the designer to be part of the implementation stage as well, and observe the fruits of their labor and directly gather feedback from the users.

4. Conclusions and Recommendations:

The comparison of engineering design and design thinking as two design frameworks revealed that they share structural and conceptual similarities. However, their differing focus on the design process stages results in each framework having its own distinct benefits and drawbacks. ED provides quick and efficient solutions for engineering problems by utilizing an analytical approach to yield timely outcomes. This is crucial for the specific nature of engineering problems that require both efficiency and thorough evaluation of solutions. On the other hand, DT, with its human-centered approach, can be more effective in generating impactful and innovative solutions for complex societal problems. The advantages of DT methods become evident in the divergence stages of the design process, resulting in co-evolving the problem and solution spaces, while ED excels during the convergence stages, narrowing down the solution space systematically.

In light of this, incorporating DT into an engineer's problem-solving toolkit can broaden their capabilities for addressing a wider range of problems. Its emphasis on human desirability and continual iterative testing serves as a counterbalance to ED's focus on technological feasibility. Engineering students can be introduced to DT as a broader framework, fostering a designerly mindset (possibly through design thinking “core” courses), before diving into the specifics of ED or any other discipline-specific ED variant in higher level courses. Furthermore, the mapping between the two frameworks presented in this study can assist students and faculty in relating the two frameworks and establishing a congruent language. However, this initial comparison may not capture all the connections between ED and DT, and future research could focus on their philosophical underpinnings.

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