Learning to innovate in uncertainty – Design thinking as a pedagogic approach to address real-world challenges in engineering education

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***Abstract*—The world is facing grand challenges often related to societal and ecological crises. These challenges are typically complex and ill-defined, and may be characterized as wicked problems, meaning that their solutions cannot deduced, i.e., there is no simple answer which solves the problem. In order to address these real-world challenges, engineers of tomorrow need the skills and mindsets to see the big picture, understand complex problems, and address these through creative problem solving. We argue that engineering education needs to apply an abductive learning approach, characterized by critical and creative thinking. In this paper we present the approach of design thinking, which we have used to support the learning process and equip engineering students with the skills necessary to address such ill-defined problems. Based on insights from our experiences from our teaching practices, we further discuss the pedagogic approach of introducing design thinking in engineering education.**

I. Introduction

To address grand challenges of today and of the future, often related to societal and ecological crises, the world increasingly needs engineers who can see the big picture, understand complex problems, and address these through sustainable solutions. The ability to develop the knowledge, skills, and mindsets to be able to solve these grand challenges in a situation of uncertainty and ambiguity is stressed by, among others, the World Bank and the OECD (see, e.g., [1, 2, 3]).

These grand challenges, which may be described as wicked problems [4], are often open-ended, characterized by complexity, uncertainty, and ambiguity. A particular characteristic of wicked problems is that their solutions cannot deduced, i.e., there is no simple answer which solves the problem. Instead of relying on deductive and analytical approaches, engineers of tomorrow need to adopt contextualized, holistic, explorative, and research-based approaches to problem-solving.

In such engineering education, engineers must develop skills, mindsets and behavior that enable them to adopt, not only expertise in certain scientific and technological disciplines, but also a broad and deep understanding of societal, humanistic, and behavioral aspects. They also need to be able to cope with unpredictable situations and uncertainty, to innovate for a sustainable future. It might even be argued that too much focus on disciplinary expertise, lacking a holistic perspective on societal and ecological implications, has led us to the climate and ecological crisis we are facing today.

In line with [5], we argue that engineering education needs to apply an abductive learning approach, characterized by critical and creative thinking, to prepare engineers to address such complex, real-world challenges. With the aim to equip students with tools and mindsets to address these types of open-ended challenges, we have worked with design thinking in undergraduate and graduate courses since 2012. In this paper we present a range of approaches of addressing wicked problems, and to support the learning process in engineering education. We further discuss the pedagogic approach using examples from our teaching practices and insights from our experiences of introducing design thinking in engineering education.

II. Design Thinking for creative problem-solving

Design Thinking (DT), put simply, is a process for innovation, which offers a human-centric approach to understand and address complex problems [6]. Design Thinking as a field has grown out of the need to tackle problem-solving in increasingly complex and ill-defined situations, and can be described as a set of mindsets, approaches, and tools, which are applied in the different phases of the design process, typically described as the understand/inspiration, explore/ideation, and materialize/ implementation phases. The process takes the starting point in creating deep insights into real, lived problems, and approaching these empathically through creative, human-centered methods of design. It is characteristically driven by an iterative approach, which oscillates between divergent and convergent phases of design, where situations and needs are researched through empathic and contextualized approaches, and ideas are developed and evaluated through visualization, prototyping and user-centered testing.

In our experience, Design Thinking lends itself ideally for understanding and addressing wicked problems. Rather than looking for the “optimum” or “correct” solution as is often the goal in many engineering situations, the design process has as its goal to find a “satisficing” solution; one that is feasible in reality. Herbert Simon noted in his Nobel Price speech that “decision makers can satisfice either by finding optimum solutions for a simplified world, or by finding satisfactory solutions for a more realistic world” [7]. The complexity of factors influencing the context of the need and thus the characteristic of the solution makes it impossible to find an optimum solution, but rather aims at finding a “satisficing” solution.

The quest of finding satisficing solutions to complex problems calls for insights into the problem, as well as creative problem-solving. John Kolko states that this process is related to abductive reasoning [8], a "process of arriving at a hypothesis to explain a given observation or to achieve a desired consequence" [9]. Design thinking therefore becomes a process of postulation – solutions are proposed based on an understanding of the requirements that define the solution, tested these against real-life situations, and the solution is iteratively adapted to meet the need. The nature of this process requires deep insight into needs and contexts and is highly driven by "intelligent guessing" to generate solutions which satisfy constraints of the real world. For example, consider the solutions necessary for addressing the UN Sustainable Development Goals. Each of these may be characterized as a wicked problem, as there is no simple or optimal solution. Rather, each require a range of approaches in various situations and contexts to collectively contribute to solving the needs of people, society, and the environment.

III. Exploring the unknown

The first phase of the process, understanding the problem, is critical to the success of the remaining work and should be devoted very particular attention. This phase is about exploring the unknown, including empathizing with people facing the problem. However, this is not intuitive for students. From our experience, students often find it hard and confusing (and sometimes even a bit annoying) not to be "served" a problem to solve, and some students don't like it at all. Furthermore, students working with challenges outside their scope of knowledge typically underestimate the time and research needed to understand a problem at a necessary depth to be able to effectively address the challenge in a sufficiently informed manner, which would enable them to successfully proceed with generating innovative solutions.

In the courses, we work with nurturing mindsets of curiosity, creative confidence, and critical thinking to encourage students empathizing with people in need finding. Through exercises in stake-holder analysis and zooming in-and-out, we encourage behaviors which counteract the often-prevalent tendency of assumption-based behavior. Instead of assuming that they know what the problem is, the students learn to expose themselves to the complexity of reality and learn by empathizing with users.

IV. Visualizing – the role and power of prototyping

Prototyping is a well-known and powerful method to test and learn about possible solutions. It also helps to build capacity for rapid experimentation and to rethink the role of failure [10]. Not only is prototyping a way to learn about strengths and weaknesses of an idea; visualizing and building prototypes also clearly supports the learning process. Prototyping can also be seen as part of the experiential learning cycle [11], where we also find active experimentation. The process of prototyping has two ends – abductive exploration of answers to a need or problem, which are tested and learned from, followed by iterative attempts to reformulate, and define a satisfying answer to the need. The approach is mainly used for discussion and communication of a solution.

In our courses we utilize simple physical prototyping material like cardboard boxes and pipe cleaners to visualize a problem or an idea. Students often surprisingly realize that, despite collaborating on the same project, they have had totally different perceptions about a concept, which make their own assumptions to surface. An interesting observation in a PhD course based on DT, was that the students in one team, when prototyping solutions, found out that they had different perceptions of the problem as well, making us realize that prototyping is a useful tool for understanding and defining the problem as well.

V. Divergent and convergent thinking

Design thinking constitutes both divergent and convergent thinking. Engineering education, however, often emphasizes the ability to reduce complexity and quickly advance to a well-defined problem definition, i.e., convergent thinking. We have seen that this tendency in engineering students may act as an obstacle to divergent thinking. For example, we found that deep previous insight into a topic can have a negative impact on the creative process. Assuming an "expert mindset" may lead to a too narrow space for exploration of solutions, often ending up in favoring technology driven solutions too early in the process. Students with deep previous insight into the project challenge tend to stick to their previously established conceptions, which typically results in ideation which renders a very limited range new ideas, or which does not question the status quo. Falling in love with your idea also hampers downstream development, which is prevented by divergent exploration and deep insight through need finding. The process of defining the need is sometimes called "problem framing". Nigel Cross notes that pre-mature problem framing, e.g., defining the challenge with too little information, may lead to ill-conceived formulations of the need and consequently to misdirected design processes [12].

VI. Discussion

Our experience using design thinking in engineering education has shown us the merit of the approach. The pedagogy, which relies on holistic thinking, experience-based learning, open-ended projects, student team collaboration, and exploration of opportunities leading to innovative ideas is an eye-opener to many students. Students often ask for the approach to be introduced earlier in their education and in more courses. While the courses are perceived as highly relevant to their education, the learning goals are, however, some time perceived as being a bit unclear. We believe that this is due to students being inexperienced in tackling open ended, real-life challenges, which necessarily are characterized by uncertainty.

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