Teaching Engineers Creativity: A Recursive Process Model for Higher Education

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Abstract: The TEC-Model (Teaching Engineers Creativity) is a recursive process model that has been developed to systematically teach a Human-Centered and iterative working style for creative problem solving to students in engineering disciplines. The model builds upon established iterative design processes with multiple phases, such as Design Thinking, the User-Centered Design Process, or the Double Diamond Model. The newly developed TEC-Model, which focuses on teaching the fuzzy process that is creativity, introduces four different iteration types with four established phases each: exploration, ideation, prototyping and evaluation. Each iteration type encompasses all phases but has a specific focus phase.

Keywords: Teaching, Engineering, Creativity, Human-Centered, Recursive Model, Higher Education

1. Future Challenges and the Necessity to Teach Creativity

Digitization and globalization, ubiquitous automation and other megatrends are changing our world of work. They—in conjunction with worldwide crises—are turning it into an increasingly volatile, uncertain, complex and ambiguous place (Adam 2021); a development that is summarized by the acronym VUCA. The aforementioned trends are affecting both the work processes and the (increasingly digital) products or outcomes of work. Obviously, the requirements and challenges that this new world poses for its inhabitants shape the demand for new solutions. As already mentioned, these trends meet crises—first and foremost climate change—that can be characterized as *wicked problems.* They defy simple solutions due to massive interdependencies, uncertainties and circularities (Lazarus 2008). The answer of many companies is to rely on interdisciplinary, agile and creative working. These changes—particularly in work practices—require a set of new competencies and skills from future employees. Teaching creative problem-solving can, however, hardly be achieved using traditional lectures. It is rather a technique that is advanced through practice. But practice takes time (Livingston 2010). As such, one must give these competencies the space to develop. A lot of research has been conducted on how to foster creativity in creative disciplines (i.e. design, architecture; for an overview see Simonton 2012). However, for technical disciplines—or STEM—a systematic approach in installing creative thinking as part of the education process is still underdeveloped (Meyer & Norman 2020). Thus, engineering education must change towards more creative thinking (Dolgopolovas & Dagienė 2021).

2. Existing Approaches and their Respective Focus

There are already numerous established approaches for iterative and Human-Centered problem-solving, such as Design Thinking (Brown 2008), the User-Centered Design Process (ISO 13407), User Experience Design (ISO 9241-210), or the Double Diamond Model (Design Council 2019). All of these models are based on the concept of multiple repetition—or iteration. Additionally, all are mapping the idea that design is not a linear process by allowing “jumps” between different phases. Finally, one of the most prominent parallels constitutes the fact that they encourage development in a Human- or User-Centered way. The common purpose of all these models is to bring systematic order into the chaos that is creative and/or problem-centered (team)work. Since the underlying process is extremely similar for all models, it is no wonder that they comprise similar phases. At the beginning, there always is a phase of understanding and researching the problem. This is facilitated by proper understanding of the context and the target group. Subsequently, requirements or needs are specified. This is expressed in various terms such as understanding, observing, planning, discovering, exploring or defining. Having understood the problem, new ideas or (design) solutions are developed. This ideation process is followed by the (prototypical) implementation of some of the ideas. Last but not least all frameworks include a test or evaluation phase. Only by involving relevant stakeholders directly in the process, one can build the basis for the next iteration and further improvement.

The models differ in the focus they place on certain aspects, be it a) User-Centered Design which concentrates on the design of interactive products with a high level of usability, b) User Experience Design which focuses on perceptions and reactions of a person resulting from the actual and/or anticipated use of a product, system or service, c) Design Thinking which builds on interdisciplinary teams and places a strong focus on understanding the problem or task, observing the people involved and building an empathic connection, or d) the Double Diamond Model that is explicitly based on the concept of divergent and convergent thinking to design the right things right.

3. The Gap and the New Approach

Obviously, with several established models already, one can argue that there really is no need for yet another procedural model. However, the aforementioned frameworks are trying to help creation and development in production ready processes. While using them in teaching, we realized that especially highly technically focused and solution-oriented engineering students have great difficulty in actually and adequately iterating when relying on these models. Oftentimes they had been working (and iterating) on a certain solution, but clearly lacked in problem definition, empathy and understanding. When used in class, students focused on a solution very early on and then spent most of their time primarily on technical implementation and refinements. However, whether the idea was actually the best solution to the problem in the particular context—or whether the identified problem was actually a relevant one—was largely disregarded. The process was usually undergone only once, and the semester—and thus the project work—ended with a mere preview of the second iteration. Users were involved, but not sufficiently integrated into the overall process. Effectively, a linear waterfall model was followed. Therefore, to push students in a mode of rapid iteration and agile working, we developed a model that simply *cannot* be completed in just one iteration. The new process was divided into different iteration types, with each type focusing on a very specific phase. The basic idea of the process model is that methods from the other phases are used to maximize the findings for the current focus phase. In this way, students should learn to deal with the various phases intuitively. Adhering to the process model, the goal is to learn the ropes of coming up with creative ideas and to build solutions by holistically understanding humans. In order to become creative on a systematic level, agile and interdisciplinary work are a prerequisite (Szostak 2017). While we try to instill this in our students, the model itself is the brainchild of an interdisciplinary team. With our professional backgrounds in Design, Cognitive Science and Ergonomics/Human Factors, we have developed and refined the TEC-Model for **T**eaching **E**ngineers **C**reativity. The TEC-Model has successfully been employed over several semesters at the Technical University of Munich.

4. Introducing the TEC-Model (Teaching Engineers Creativity)

The TEC-Model is—in contrast to existing ones—not iterative, but recursive. This does not only fit well with pre-existing concepts taught to engineers, but also signifies the importance of repetition without doing the exact same thing over and over again. As such, the TEC-Model describes four different iteration types that all have to be finished in order to consider the application of the model complete. Each of the iteration types consists of four phases, namely *exploration*, *ideation*, *prototyping* and *evaluation*. The iteration types differ in their focus, however, and each has an explicit focus phase. More specifically, the first iteration type focuses on exploration, with short ideation, prototyping and evaluation phases. The second iteration type subsequently only employs a short exploration phase, while focusing on ideation. Prototyping and evaluation are then conducted in a quick manner. Similarly, the third iteration type focuses prototyping, the fourth iteration type focuses evaluation. It is possible to jump between different phases within an iteration but also between the different iteration types, if necessary. A graphical representation of the entire model can be seen in Figure 1. The individual iteration types are described in more detail below. The overarching theme is the use of methods from different phases to maximize learning in the current focus phase. A set of methods that might be useful to foster learning for the different focus phases is listed in Table 1. Additional methods, including the ones for utilization within the focus phase, can be found for example in the IDEO Design Kit.

Iteration Type 1 | Focus on Exploration: Iteration type 1 is first and foremost about identifying the *underlying* problem, as well as getting to know and holistically understand the context and the people involved. Close contact with the users is essential throughout the process. In the beginning, the goal is to identify the underlying needs of users in order to be able to develop a novel and useful solution in a targeted

Figure 1: The recursive TEC-Model for Teaching Engineers Creativity.

manner. This then has the potential to become an innovation. After a comprehensive exploration, ideation tools and methods should be used to better understand the problem. Initial prototypes should be created to enable clear communication with users and get initial qualitative feedback to specify the problem. At the end of iteration type 1 students should understand the context, the users and the problem, have identified needs and stakeholders and have mastered the changing of perspective to frame the design challenge.

Iteration Type 2 | Focus on Ideation: After the context, the user group, and the basic assumptions from iteration type 1 have been secured in a short exploration, the next step is to develop creative ideas for solving the problem. The key at this stage is to think outside the box, be creative, open-minded, and come up with as many ideas as possible. Radical, wild ideas should be encouraged and be utilized as stepping stones to build on the ideas of others. During the ideation sessions, there must be an open, non-judgmental atmosphere. Ideally, different idea generation methods are used, and the ideas are visualized. Different methods might work differently well for different teams. At the end of the ideation session, several (at least three) ideas for a wide range of prototypes should be chosen to avoid losing innovation potential. During the prototyping phase, some ideas should be filtered and made tangible, and then a rapid evaluation should be conducted to gather feedback as well as test and adjust ideas. After iteration type 2, students should have applied several methods of idea generation and filtering and have learned how recombination of technologies and principles lead to new ideas. Some (again, more than one) ideas should have been selected to continue with.

Iteration Type 3 | Focus on Prototyping: In the exploration phase, the assumptions should be briefly reviewed. Subsequently, ideas for the realization of the prototypes that will be developed in the focus phase should be generated. Prototypes should be built to make ideas tangible. We understand a prototype as one manifestation of an idea that allows users and other stakeholders to experience and understand it in order to explore its suitability. It can be anything that makes the idea tangible, such as a sketch, a storyboard, a video, an object, a digital click dummy or a role play. Any prototype needs a specific purpose—or in other words: something that is to be gained from producing it. This can range from communication (be it within the team, or to outsiders) over facilitating problem understanding to evaluating the entire solution. Materials should be used that move at the speed of thought, since building prototypes can help to better understand the ideas. One should always be prepared to completely scrap a prototype, and never fall in love with it, as it is only a means to an end. In a short evaluation, prototypes should be tested, and feedback should be gathered. At the end of iteration type 3, students should have understood the complexity within their ideas and be aware of hurdles that might hinder realization. There should be several quickly evaluated prototypes that can stand for themselves and communicate the idea(s).

Iteration Type 4 | Focus on Evaluation: In a quick exploration it should be ensured that the right user group, context and needs are addressed. Within the ideation session, ideas are to be generated for conducting the evaluation. The evaluation should be constructed in a visual and tangible way. The (main) evaluation must be planned carefully. Formative and summative approaches, qualitative and quantitative data, as well as analytical and empirical methods should be used purposefully. Comprehensive evaluations are required to learn how users interact with a product or service and whether they like it. It is essential to listen to users and to show rather than explain. It is advisable to let users compare alternatives and one should never try to convince.

Table 1: *Suggested methods to facilitate the learnings of the focus phase in additional phases for each iteration type.*

	Exploration	**Ideation**	**Prototyping**	**Evaluation**
Iteration Type 1	—	- Brainstorming - Create Insight Statements	- Rapid Prototyping - Storyboard	- Get Feedback
Iteration Type 2	- Analogous Inspiration - Extreme Interview	—	- Rapid Prototyping - Role Play	- Cognitive Walkthrough - Questionnaires
Iteration Type 3	- Observation - Focus Group	- Journey Map - Co-Creation	—	- Heuristic Evaluation - Thinking Aloud
Iteration Type 4	- Immersion - Card Sort	- Storyboard - Co-Creation	- Wizard of Oz - Role Play	—

users of an idea or solution. All decisions should be data-driven. Thus, students should have understood how to quantify and critically review their ideas. For this, they need to learn how to distance themselves from ideas and adequately interpret feedback. And since the best design is the next one, if after iteration type 4 the perfect solution is not yet found, the next cycle of iteration types can be started.

5. Lessons Learned and Students Taught

After application and refinement of the TEC-Model in more than three years of teaching, we can confidently conclude that the current version of the model is suitable for teaching concepts of creative problem solving to engineering students. The fact that this model is clearly made for teaching rather than actual development encourages students to explore different methods, options and rethink the solutions they are building. Oftentimes, our teams of interdisciplinary students felt confident in their initial approaches, only to discover later on that a restart with different underlying needs, addressing a different problem was necessary. The model thus facilitates intuitive understanding of the interdisciplinary, agile, and yes, sometimes chaotic phenomenon that is creativity (Prasch 2022).

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