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Defining technical creativity: iterative development of a shared understanding

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ABSTRACT: Creativity is a requirement for excellence in product engineering. Despite its important role, the concept of creativity in engineering is challenging to articulate and define, both for practitioners and researchers. What makes technical creativity unique? Existing definitions often fall short of capturing the essence of creativity in technical contexts. The process of defining technical creativity is performed iteratively. In product engineering, creativity is not an abstract concept but a practical necessity, requiring motivation, imagination, expertise and experience. Therefore, two workshops with product engineers were held and the results were used to refine the definition. A shared understanding of technical creativity, that can be applied in daily engineering practice is created, enhancing both research and practical outcomes in product engineering.

KEYWORDS: defining technical creativity, product engineering, creativity, design engineering, design practice

1. Introduction

Being creative is one of the prerequisites for good results in product engineering (Alahuhta et al., 2014; Wang et al., 2019). Product engineers are required to come up with new solutions and designs for systems, services or processes on a daily basis, but product engineering is not the only technical field in which being creative is highly important. When talking to engineers from different fields, it becomes clear that their problem-solving tasks also require creativity. Talking about creativity with experts from a variety of different technical fields shows that creativity is everywhere. Although creativity plays a crucial role, it is challenging to effectively communicate what creativity precisely means in its characterization as experienced by product engineering but also in other technical fields. Both practitioners and design researchers find it difficult to grasp and articulate the essence of this specific creativity. For researching creativity in a product engineering context, it is important to clarify its core question: What is it that makes this creativity special that for example product engineers have? As this kind of creativity arises in technical fields, this could give a first hint, but existing definitions of technical creativity don't explain its concept. Mujika et al. (2014) for example speak about the technical creativity of their students in a biochemical laboratory, but without explaining what characterizes this technical creativity. An attempt to transfer Henry Bergson's (Bergson et al., 2007; Bergson et al., 2013) understanding of creativity from philosophy to engineering results in an unconcreted definition of technical creativity, not referring to the phenomenon in everyday engineering practice (Telivuo, 2024). This contribution aims to define technical creativity through an iterative process, starting with the state of the research as a basis.

2. Understanding creativity

Creativity is a multifaceted and widely researched phenomenon. It plays a pivotal role in driving innovation across various domains. The concept of creativity is described differently by various disciplines and the perspectives on creativity vary across different cultures. Consequently, there are numerous definitions of creativity in literature. In this section, we delve into the existing body of knowledge on creativity, exploring its general principles and understandings. Section 2.1 provides an overview of creativity, examining its fundamental concepts, underlying mechanisms, and influential factors. Section 2.2 then narrows the focus to creativity within the context of product engineering, highlighting the differences between different understandings and the lack of an applicable definition of technical creativity.

2.1. Creativity in general

Stein (1953) describes creativity as generating something novel that is accepted as useful by a group. Novelty involves aspects that have not previously existed in the same form and can result from the recombination of existing knowledge while introducing new elements. Creativity is also a psychological construct that is subject to various interpretations, encompassing the four Ps: Product, People, Process, and Press (environment) (Rhodes, 1961). It is further understood as a divergent thinking process, where many possible solutions are generated without following a linear pattern (Alahuhta et al., 2014; Elliot & Nakata, 2013; Ocker, 2005; Paletz & Peng, 2008; Wang et al., 2019). This thinking process can be distinguished between individual and group creativity. Individual creativity is influenced by cognitive abilities such as fluency, flexibility, originality, and elaboration, as well as personality traits. Characteristics that enhance creativity include autonomy, self-confidence, and intellectual honesty. Additionally, intrinsic motivation significantly impacts creativity. The group's ability to accomplish a creative task is influenced by individual creativity. Furthermore, factors like group composition, its characteristics and processes, and the contextual influence affect this ability. Generally, the potential for idea generation within a team is higher compared to an individual. (Alahuhta et al., 2014; Chamakiotis et al., 2010; Ocker, 2005) Furthermore, various researchers state that culture influences creativity (Glaveanu et al., 2020; Hofstede et al., 2010; Rhodes, 1961). In the Western world, creativity is perceived as a capability, a cognitive trait, or a process involving investment, confirmation, and interpretation. In East Asian cultures, creativity is characterized as a mental attribute for acquiring information, building understanding, and applying new solutions to problems. (Gong et al., 2023; Lubart, 1999; Niu & Sternberg, 2001; Paletz & Peng, 2008) However, Paletz and Peng (2008) highlight the differences within East Asian cultures, which lead to varying perspectives on creativity. To conclude, creativity has no common definition, due to its multifaced properties. In the context of this work, Stein (1953) is used as the underlying understanding of creativity (see Figure 1) since it is open to all fields and application options and therefore does not limit creativity to a specific use.

> Creativity is the skill to create something **novel** that is **accepted** as **tenable or useful or satisfying by a group in some point in time**. Novel signifies that the output of being creative did not exist previously in the exact same form. Something novel is based on the reintegration of existing materials or knowledge, but after being creative, it contains new elements.
> (based on Stein, 1953, pp. 311-316)

Figure 1. Definition of creativity based on Stein 1953

2.2. Creativity in the context of product engineering

In product engineering, creativity is not merely an abstract concept but a practical necessity. The field requires the integration of technical knowledge with inventive thinking to design and develop products that meet user needs and market demands. These points are summarized in the innovation understanding of Albers, Heimicke, Walter, et al. (2018), which is based on Schumpeter (1912). The understanding refers to a successful and novel product: A described need (product profile) that is developed (invention) and successfully brought to market. Therefore, product engineering consists of strategic product planning, product development, and production system development (Albers & Gausemeier, 2012). Within this, creativity incorporates a crucial role in product engineering and is needed in all three of the above-mentioned elements of innovation (MacGregor & Torres-Coronas, 2007).

Within design literature, creativity is linked to outcomes (i.e., the creative product), individuals (i.e., the designer), and processes (i.e., the creative process) (Chamakiotis et al., 2010) and is seen as a crucial element by various authors (Howard et al., 2008; MacGregor & Torres-Coronas, 2007). The Integrated

Product Development Model (iPeM) portrays product development as a complex endeavor that integrates various disciplines and interfaces with operational, knowledge management, and improvement processes (Albers et al., 2016; Deigendesch, 2009). In this context, development teams must address multiple requirements and constraints, often implicit within the system of objectives (Deigendesch, 2009). Creative product development teams generate new ideas and solutions, offering products with high innovation potential to their markets. Solutions to problems frequently arise from the integration of existing products and processes, demonstrating that product development is a problem-solving process characterized by generative steps leading to alternative solutions (Albers, 2010; Albers et al., 2002; Ehrlenspiel & Meerkamm, 2017; Pahl & Beitz, 1997; VDI Verein Deutscher Ingenieure e.V [The Association of German Engineers], 2019). In design literature Chakrabarti (2006) concludes that creativity can be influenced at the skill level, the level of methods, and the level of stimuli which often come into play at the same time when talking about understanding creativity in product engineering. When looking more towards the level of prerequisites for creativity, therefore starting the discussion of influences on creativity at an even earlier point the knowledge of the creative individual comes into play, here both the design knowledge of the process as well as the product (Chamakiotis et al., 2010) are relevant (Venkataraman et al., 2015).

Existing literature identifies both factors that enhance creativity and barriers to creativity encountered in product engineering. Part of the author team (Bastian et al., 2023) conducted a systematic literature review and categorized success factors and barriers into clusters: Team, Individual, Organization, Culture, Leadership, Technology, and Time. With the variety of influencing factors at hand, it becomes clear that also in the context of product engineering creativity is a multifaced phenomenon.

None of the existing definitions of creativity in the product engineering context actually grasps what makes the creativity that engineers but also craftsmen have special. Since this specific creativity seems to only exist in the technical field, technical creativity might be the right term to describe it.

The term technical creativity can be found in the engineering context, showing that creativity in technical contexts is a specific kind of creativity. But the use of the term does not explain the concept of it and a suitable definition is not given. In their work, Mujika et al. (2014) explore the technical creativity exhibited by students in a biochemical laboratory. However, the authors do not explicitly delineate the defining characteristics of this technical creativity. Drawing inspiration from the philosophical insights of Nobel laureate Henry Bergson, the study attempts to elucidate the concept of technical creativity across 33 pages (Telivuo, 2024). Despite this effort, a precise definition of the everyday engineering phenomenon of technical creativity remains elusive.

3. Research design

3.1. Research aim and research questions

As shown in section 2, the terms creativity and technical creativity are discussed in various communities. Especially creativity shares a vast number of definitions. As described, the definition introduced by Stein (1953) unites most of the given understandings and builds a baseline for many recent definitions. Therefore, it is chosen as the baseline for further investigation.

Technical creativity isn't as clearly defined yet as it shows different perspectives on respective authors' interpretation and view of technical creativity. Yet, the definitions do not match the development reality in engineering environments and are not compatible with established processes, methods and tools from product engineering.

Already proposed definitions of technical creativity lack a clear wording and targeted delimitation from the next higher category and related terms, their definition of application and their relation to the technical field.

Therefore, the aim of this study is to find a definition of technical creativity that suits the existing and established understanding of creativity and unites the current understanding of engineering practice. With this definition, communication about technical creativity should be made easier not only for the ones applying it regularly but also for people external to this context. In addition, future research should be facilitated. This leads to the following research question:

RQ: How can technical creativity be defined in general and what are the unique aspects of technical creativity in the context of product engineering?

3.2. Research approach

Based on the approach of Dahlberg (Dahlberg, 1981) and the problem-solving methodology SPALTEN (Albers et al., 2016), Albers et al. propose a definition process that will be used in this contribution (Albert et al., 2023).

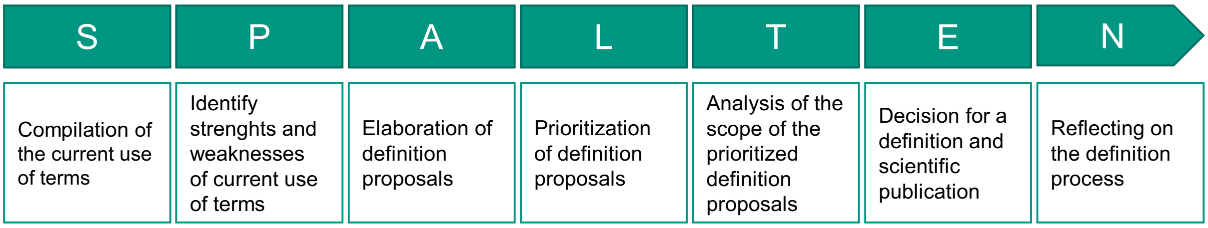

Figure 2. Approach to a definition based on SPALTEN, based on Albert et al. (2023)

To emphasize the iterative character of SPALTEN and display in more detail in which steps the iterations have been made Figure 3 shows the detailed approach.

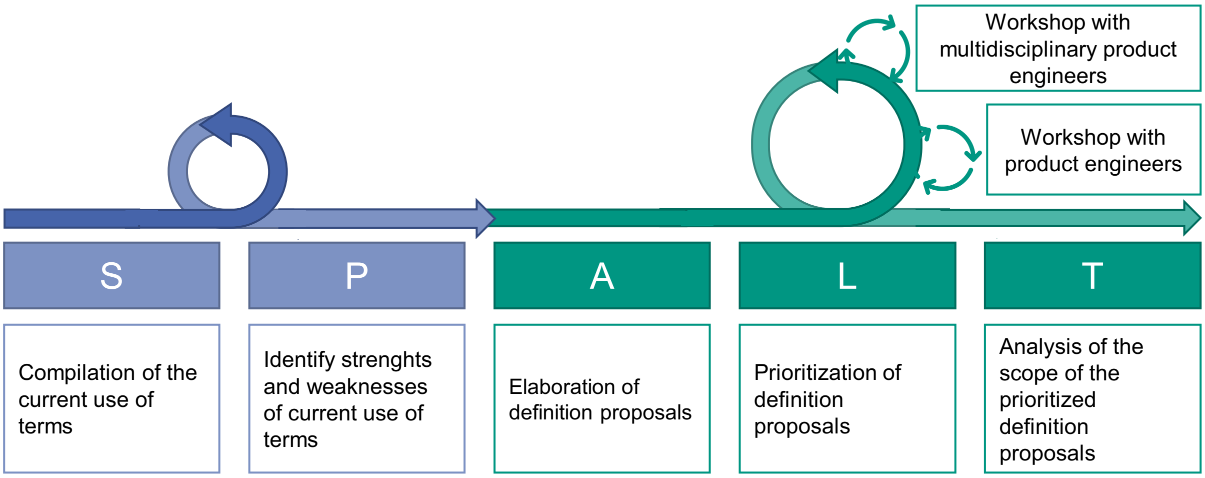

Figure 3. Iterative approach to the definition of technical creativity based on SPALTEN

The process of defining technical creativity is initiated through a literature review of already-known definitions. The results of this review build the basis for section 2. Based on the definitions already discussed, a first proposal for a definition of technical creativity is given.

During a workshop with product engineers with expertise in design science, the given definition is discussed. With the input from the involved product engineers, the initial definition is refined and iterated to propose a new definition based on the practical insights and new findings.

In a second iteration, the refined definition is discussed in a multidisciplinary workshop with engineers from different fields in the context of product engineering. The fields span from design engineering to systems engineering, to system tribology, fuel cell development and human-machine systems. As in the first iteration, the feedback is used to iterate into a finalized version of the definition of technical creativity presented in this work.

4. Understanding technical creativity - results

Based on the definitions found in the literature and on the research gap, an initial definition is designed. The goal of this definition is to clearly define what lies behind technical creativity and the way it is applied continuously in many technical fields.

The definition includes the aspect that technical creativity needs to not only be new but also have a certain predefined benefit. Furthermore, the initial definition lays the focus on technical creativity representing a solution to a concrete problem. Technical creativity is differentiated through the technical knowledge needed within a team, so the team is able to be technically creative. Examples of which criteria the output of technical creativity needs to meet are given: technical, economic, ecological, social, legal and aesthetic.

4.1. Iteration 1: workshop product engineers specialized in development methods

After coming up with the initial definition, it is presented by the author team in an online workshop session with 14 product engineers with expertise in design science. We understand design science as the interdisciplinary field of design research, design teaching, and design practice for the development of innovative solutions. All of the experts have experience in at least two of the fields mentioned above. All workshop attendees actively engage in engineering projects and research methods, where technical creativity plays a central role in problem-solving processes. Being creative in the sense of technical creativity is a natural part of their everyday work.

The definition was presented in PowerPoint with the differentiations of the definition. The differentiations are marked in colors to make structuring the discussion easier.

The session was recorded and the participants had the opportunity to share their thoughts, discuss the thoughts presented by the others and ask questions to the authors. The open format was chosen to make sure that all different opinions and assessments can be heard, discussed and put in perspective together. After the session, the author team re-visited the comments on the differentiations one by one, discussed the arguments and systematically made the following improvements:

1) Technical creativity is not only relevant in product engineering. Other technical fields apply it in the same way, and therefore the definition does need an addition that explains technical creativity specifically in product engineering. With such an example of the expression of technical creativity in the product engineering context, it will be easier to apply and actually use the definition. It has been made clear, that product engineers are more likely to use and refer to the definition if they see their own use case. Since the authors themselves are product engineers, the application example for product engineering is given in the following in more detail. This does not mean that other application fields are less relevant. Therefore, examples from the other application fields will be introduced later as well, but with the goal of making clear what falls into technical creativity and what does not.
2) The restriction of creativity having a defined benefit is not precise enough. The benefit might be defined, but what differentiates technical creativity here is that it is targeted to a certain goal. Therefore, this aspect is rewritten stating that technical creativity is “targeted creativity”.
3) In the initial description, the use of technical creativity is the creation of a solution to a concrete problem. This description is found to not include all aspects of the use of technical creativity. Technical creativity is used in analysis and synthesis steps, somebody can be technically creative without finding the solution to a certain problem directly.
4) The definition should include that technical creativity is not limited to analyzing and synthesizing systems but processes as well.
5) The necessity for certain criteria for possible solutions to be considered technically creative was seen as problematic. The selection of certain examples makes the reader think of other criteria without knowing if these are included or not. Therefore, the clear statement that technical creativity can be applied in all technical fields has been added, whilst the examples for criteria are removed.

4.2. Iteration 2: workshop product engineers from different fields

The updated definition that was created with the feedback from the first workshop was presented by the author team in a second workshop. The workshop was conducted in an onsite session in a deep work setting during the yearly three-day internal conference held by the Institute of Product Engineering. The eleven engineers who participated in the workshop are from different fields in the context of product engineering. The fields span from design engineering to systems engineering, to system tribology, fuel cell development, and human-machine systems. The definition was presented using PowerPoint and with the differentiations of the definition marked in colors, similar to the first workshop iteration described in section 4.1. Additionally, a whiteboard and paper cards were used to collect ideas. The board was divided into two sections where participants could pin their notes when introducing their thoughts: technical creativity and technical creativity in product engineering.

The results on the whiteboard were collected and the discussion was documented by the authors. For this workshop, the method Think-Pair-Share (Macke, Gerd, 1939- et al., 2016) was chosen to collect and

discuss ideas. The reason for using this method is to give the workshop a more structured discussion style and accommodate the different engineers' personalities.
In the "Think"-phase, the participants were given ten minutes to collect their ideas on the paper cards individually in silence.
In the "Pair"-phase, another 15 minutes were given to discuss their results with an engineer from a different field. In the discussion, the partners were asked to share their thoughts, add additional cards or remove some from their collection.
In the "Share"-phase, each pair of engineers presented their results while the listeners had the opportunity to ask questions. The presenting team pinned their cards to the whiteboard and was instructed to cluster similar cards.
After the "Think-Pair-Share"-part of the workshop, all workshop attendees discussed open questions in an open discussion moderated by the authors to ensure all questions were asked and all opinions and thoughts were heard. The engineers were instructed to think of their own daily appliance of technical creativity when discussing.
The goal of the workshop was to hear the different characterizations of technical creativity in various fields to make sure the definition does not exclude any aspects of technical creativity.
After the session, the author team re-visited the paper cards and the documentation of their arrangement as well as the notes taken, discussed the arguments and systematically made the following improvements:

1) It was found that the definition was not framed actively enough. The formulation that included "applying technical creativity" was changed to "being technically creative" to make sure that the definition sets the creative act in the focus.
2) The restriction of technical creativity being targeted creativity has been found not to be precise enough, which seems similar to the improvement point in the first workshop iteration. The attendees state that the definition of technical creativity should make clear that being directed to a certain target is not the same as having a certain objective. The two aspects had relevant differences to the experts. Therefore, the improvements made in the second iteration include technical creativity as "targeted creativity" as well as "with a certain objective". By including both aspects in the finetuning of the definition applicability in the different fields of the experts is made sure. Since this is one of the critical points, the highest sensitivity in including the aspects was applied.
3) The experts saw giving examples for the technical fields in which technical creativity is present as enriching to the definition. They stated that especially the technically creative minds in craftmanship feel more called to use the definition if their field of application is explicitly mentioned. This discussion included that technical creativity is not limited to the field of academia at all. It is open to all technical fields. To put emphasis on this aspect, craftsmanship has been used as one of the examples.
4) Another major change relevant to the participants was that the prerequisites for technical creativity need to be made clearer to differentiate technical creativity from creativity in general. The requirements found by the experts are motivation, imagination, experience and expertise. These aspects are clarified in the following example (see Figure 4).

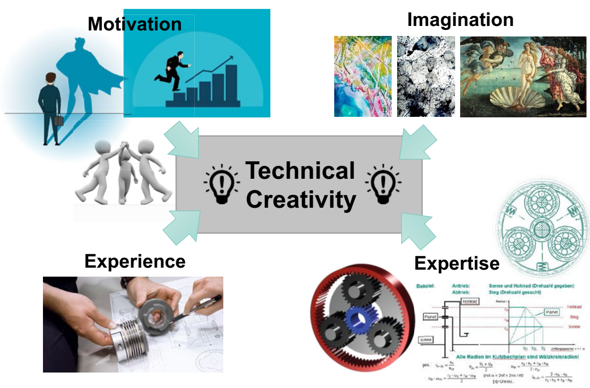

Figure 4. Requirements for technical creativity

Motivation and imagination are needed for all kinds of creativity but experience and expertise are specific for technical creativity. Motivation describes the feeling *of "I want to do it, I can do it and I am enabled to do it"* (A. Albers, personal communication) within a human. The motivation to be creative needs to exist intrinsically, a human should want to be creative. If that is the case extrinsic factors can increase the motivation further by setting the necessary boundary conditions for creativity. Factors that can improve extrinsic motivation are for example a working environment that allows for creative thought, a space without time pressure, a company culture that openly deals with mistakes also from top down, or a designated time to say unfiltered thoughts out loud. If a human is intrinsically motivated and the boundary condition fits its needs, then the ideas that come from this creative process have a high potential to be elaborated further.
The two prerequisites that are specific to technical creativity can be explained further by giving examples of what falls into the technical field. A stonemason needs technical creativity to shape stones and build stable structures that match the architect's design. Similarly, the architect also needs technical creativity to come up with the design. The architect is technically creative when finding a design solution for the structures whilst the stonemason is technically creative when forming the stones into shapes that ensure stability, and durability. Both of them were able to be technically creative before the laws of physics were discovered, which lay behind the complex structures of medieval cathedrals. This example proves that technical creativity does not necessarily need the explicit knowledge taught in academic education. What was needed in this example was the experience and expertise of these craftsmen as well as their imagination for their achievements.

5) Under this aspect, the relevance of mentioning the technical fields within this definition explicitly has been discussed again. Artists and musicians need experience with their specific musical instrument as well as the expertise to use it properly. They might have the imagination to come up with a new song, making them very creative, but not technically creative.

4.3. The resulting definition of technical creativity

Based on the results of the workshop iterations explained in sections 4.1 and 4.2, the final definition of technical creativity is introduced in Figure 5.

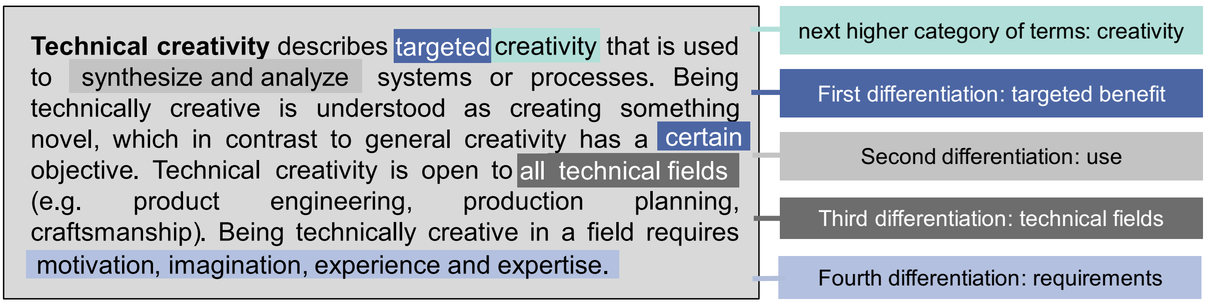

Figure 5. Definition technical creativity

4.4. Technical creativity in the context of product engineering

Section 4.1 raises the relevance of providing insights for applying technical creativity in the product engineering context. While such a classification holds relevance for other specific contexts it should ideally be proposed by domain experts in each relevant field.
Specifically for the product engineering context based on Albers, Heimicke, Hirschter, et al. (2018) an understanding of technical creativity is created (see Figure 6).

> **Technical creativity in product engineering** describes technical creativity in analysis and synthesis processes within all elements of innovation. It is understood as the creativity needed to create a reference system, a product profile, an invention, or concepts for a market launch.

Figure 6. Understanding of technical creativity in the context of product engineering

5. Discussion

The main focus of the process to the final definition was to combine multiple perspectives on technical creativity to make sure, that the definition reflects the phenomenon of technical creativity. The literature-based initial definition was needed to have a starting point for the discussions with the experts. It is crucial to be open to far-reaching adaptions to make the definition match the reality. One major takeaway regards the open discussion style in the first workshop. With a bigger group with even more diverging opinions, this discussion style is not suitable. Moderating an open discussion with experts can lead to difficulties in guiding the conversation forward and can result in an unstructured jumping back and forth in the different parts of the definition. The recording of the first workshop needed to be played multiple times to grasp and evaluate all relevant aspects. The recommendation would be to have an open discussion only in groups of less than five experts and use a more structured approach in bigger groups. The discussion not being easy to follow or manage is one of the reasons for the use of the Think-Pair-Share method in the second workshop. The support of the method ensured more structure and that all voices were being heard.

Another recommendation is that the revision of the results of the workshops should always be done by more than one person. When discussing the results, there are always some aspects that depend on the individual interpretation of a person. Therefore, it is important to discuss potential changes before they are implemented with others familiar with the context. In some cases, asking the participants again for clarification was necessary to ensure that the information was processed in the way it was meant.

The definition of technical creativity resulting from this process is suitable for a variety of contexts from product engineering to production planning and craftsmanship. To distinguish the resulting application of the definition, four differentiating examples are given to clarify each differentiation within the definition. This is crucial for understanding the areas of application of technical creativity:

1) Musicians writing a new song are not technically creative. They are creative and they are artists for sure but they do not fall into the technical context and are therefore not considered technically creative.
2) The luthier on the other side, who applies his technical expertise and experience and uses his imagination to create a new instrument is technically creative.
3) The child who draws a picture might be creative but not technically creative since it is neither in the technical context nor working towards a targeted benefit. Readers might say that making the mother happy with the picture is a certain objective but the example is still lacking the technical context.
4) The final example is the mechanic repairing a car. The mechanic is working in the technical context but for his work to be technically creative one of the requirements is not fulfilled, and that is imagination. Whenever the mechanic performs a task where he is following a step-by-step plan, he is not technically creative. That does not mean, that a mechanic cannot be technically creative. There are problems to be solved for mechanics that require imagination and therefore involve technical creativity to find a solution.

Furthermore, motivation is needed to be technically creative, but just like imagination, motivation is a prerequisite for creativity in general as well.

6. Conclusion and outlook

A multitude of definitions of creativity exists where some are very general and some are context-dependent. This includes definitions for technical creativity, but none of those grasp the concept of technical creativity the way it is applied in engineering practice. The three-step process described in section 3.2 was designed to fill this gap and to come up with a definition that makes the concept of technical creativity clear and usable. By usable we mean making technical creativity a term that individuals in technical fields identify with and can communicate about to improve possibilities to learn from them and to enable designing targeted support for their kind of creativity as a prerequisite for innovation. The initial definition was proposed based on a literature review. This definition was presented in a workshop with product engineers with expertise in design science and refined with their annotations. The resulting version of the definition was discussed in another workshop with engineers

from different fields in the context of product engineering. This resulted in the definition introduced in section 4.3.
The next step is to discuss the definition with people with more diverse backgrounds who all apply technical creativity in their profession. The goal of this next step is to see if technically creative professionals from different fields can see their technical creativity reflected within the definition. Furthermore, discussing the definition with international experts who are technically creative is another relevant next step. Within the process, initial discussions with international design engineers have been held but a broader systematic evaluation could bring further insights concerning applicability.

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