Tinkering, Tools and Techniques – Creativity in German Engineering Education

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ABSTRACT

Purpose – Engineers are expected to be the creative problem solvers and innovative tinkerers of a company. This article examines to what extent German tertiary education lives up to this expectation. The analysis of German module descriptions in engineering shows that there are no courses dedicated to creativity and that creativity and its techniques are mentioned only sparsely in the modules of the engineering curriculum. Surveys amongst our students show that they are usually familiar with techniques which are based on generating alternatives such as brainstorming and morphological box, but lack knowledge about techniques based on challenging assumptions such as forced connection. They tend to favour discursive techniques over intuitive ones and techniques which use generation of alternatives as an idea-generating principle. A combination of creativity techniques seems to be most conducive to creative output in our course. Finally, we present some first findings on creative sessions in remote work with the help of virtual whiteboards, which have gained in importance since the pandemic.

Methodology – Firstly, we present an document analysis of the modules of Bachelor and Master programs of mechanical engineering at German universities and universities of applied sciences. Secondly, we present results from surveys in our Master course in "Innovation and Technology Management" where we gathered data from students over several years and performed an external evaluation of the output using Consensual Assessment Technique (CAT). These results include which creativity techniques the students know prior to the course and which they prefer as well as which techniques seem to be conducive to engineering creativity. Furthermore we surveyed their experiences with creative sessions as remote work.

Conclusion – Overall, the article shows the importance to teach prospective engineers the basics in creativity. Students should have the opportunity to acquire knowledge about and apply different creativity techniques, as different techniques have different strengths and weaknesses and thus, different areas of fruitful application. They should also have the chance to try out different modes such as in-person sessions and virtual sessions, as some of the future work will most likely shift online. Furthermore, a combination of different creativity techniques makes it more likely that engineers break through their usual systematic-analytic way of thinking and helps them to think outside the box to find creative solutions for the pressing problems of our time.

Keywords: Creativity, Engineering, Education

1 Introduction – What do we expect from engineers?

Engineering can be understood as a special case of a more general process of creative problem solving (Cropley, 2015). Engineers are typically the persons in a company who develop new products and processes by adapting scientific principles to specific problems (Seelinger, 2004). Some people – e.g. the former steel tycoon Ekkehard Schulz (2010) – even go so far as to compare engineers to artists, since they both work

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creatively, intuitively and imaginatively. Despite the differences that some researchers see in the creativity of different domains, engineers are expected to be the creative problem-solvers in their respective organizations and the drivers for innovation by developing and applying new technologies.

According to Runco & Jaeger (2012) the standard definition of creativity includes two characteristics: originality and effectiveness. This means that a creative solution has to be novel, original and surprising as well as effective, valuable and suitable (Deckert 2016). In engineering the emphasis is typically on effectiveness, as engineers strive to find a solution to a pressing technical problem. For the field of engineering, Cropley & Cropley (2010) use the term "functional creativity" to distinguish creativity with a functional purpose from mainly aesthetic creativity. Functional creativity leads to industrial products and services such a machines or consumer goods.

Amabile (1996) distinguishes three components of creativity: expertise, creativity skills and task motivation. Expertise and motivation are domain-specific, i.e. they depend on the professional discipline where one wants to be creative. In the case of engineering, expertise encompasses engineering skills usually taught in a technical university and motivation is confined to engineering tasks. Creativity skills, however, are valid across several domains and can be taught via approaches for creative problem solving or creativity techniques. There are several strategies in creative problem solving such as synectic or morphological approaches (Geschka & Lantelme, 2005). One approach often taken by engineers is Creative Problem Solving (CPS) based on the approach of Alex Osborne, the creator of brainstorming. This approach can be roughly divided into three phases of problem definition, idea finding and solution implementation (Isaaksen & Treffinger, 2004).

Creative thinking can be supported by creativity techniques. In the strategies of creative problem solving, creativity techniques are usually a major part. Creativity techniques are based on idea-generating heuristic principles such as association, imagination, combination and confrontation (Geschka & Lantelme 2005, Geschka & Zirm, 2011). Those principles can be aggregated to two main principles proposed by de Bono (1991) to distinguish between techniques that help to generate many alternatives and techniques that support the challenging of assumptions (Deckert & Mohya, 2020a). Furthermore creativity techniques can be divided into intuitive techniques characterized by spontaneous insights from the subconscious (e.g. brainstorming) and discursive techniques characterized by their systematic and analytical approach (e.g. morphological box) (Brem & Brem, 2013). Additionally inventors often use heuristics to find solutions, and there are lists of heuristics such as SCAMPER and the universal TRIZ-principles. Furthermore, there are also collections of inventive heuristics in the literature, e.g. "always consider the negative" or "consider the ideal solution", which can be structured according to the two main principles of creativity (Deckert 2017, 2018). Fig. 1 gives an overview of some of the main creativity techniques and collections of heuristics. So we should expect engineers to be well-educated in the approaches of creative problem solving and creativity techniques.

From the starting question of what we expect from engineers we derived the following key questions to guide our research:

- What do we teach prospective engineers with regard to creativity?
- What do our students know about creativity?
- What enables our students to be more creative?
- What changes are there in creative problem solving due to remote work?

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	intuitive	discursive	heuristic
Generation of alternatives	Brainstorming Brainwriting 6-3-5 Method Mindmapping	Morphological box	SCAMPER
Challenging assumptions	Reversal method/ Anti-solution Forced connection	Theory of inventive problem solving (TIPS/TRIZ)	Heuristic principles of TIPS/TRIZ

Figure 1: *Creativity Techniques and Heuristics (Deckert & Mohya, 2020b)*

2 What do We Teach Prospective Engineers?

Creativity can be conveyed by teaching different creativity techniques in the context of general strategies of creative problem solving and reflecting on their advantages and disadvantages (Geschka & Lantelme, 2005). It can also by taught by adequate teaching and examination methods such as case studies, group discussions, role play and projects (Kirillov, Leontyeva & Moiseenko, 2015) as well as by focusing on the problem-solving process through the work on open and ambiguous problems and the active inclusion of students' ideas in the process (Papaleontiou-Louca *et al.*, 2014). Furthermore creativity can be supported by a creativity-enhancing work environment which supports the initiative of the students to start their own projects (Papaleontiou-Louca *et al.* 2014) – a concept similar to the "Corporate Creativity"-approach by Robinson & Stern (1997). However, a central element with regard to content are creativity techniques.

To find out what prospective engineers are being taught in German tertiary education, we conducted an analysis of the module descriptions of the largest German universities and universities of applied sciences with a mechanical engineering department. In this analysis we focused on the occurrence of the word "creative" and "creativity" as well as main creativity techniques in the module descriptions. In total, we looked at the content of Bachelor and Master programs of 20 universities and universities of applied sciences with regard to creativity (Deckert, Kuppuswamy & Wigger, 2020, Deckert, Maschmann & Ngoy, 2021).

As a main result, we found that no course is completely dedicated to creativity (i.e. creativity as part of the course title). All in all, only a small fraction of the modules included creativity or creativity techniques in their descriptions. In the Bachelor programs, five universities of applied sciences and eight universities had no content on creativity techniques in their module descriptions at all. Likewise in the Master programs, five universities of applied sciences and six universities had no modules with any content on creativity techniques whatsoever. The most common creativity techniques are the morphological box and the TRIZ/TIPS -methodology indicating a preference of discursive creativity techniques over intuitive techniques (Deckert, Kuppuswamy & Wigger 2020, Deckert, Maschmann & Ngoy, 2021).

3 What do Our Students Know About Creativity?

In our Master course "Innovation & Technology Management" we continuously ask our students which creativity techniques they already know from their Bachelor study programs, before we teach them different creativity techniques. The assessment of the degree of familiarity looks similar in every term. Fig. 2 shows the aggregate results of the summer terms 2019 to 2022.

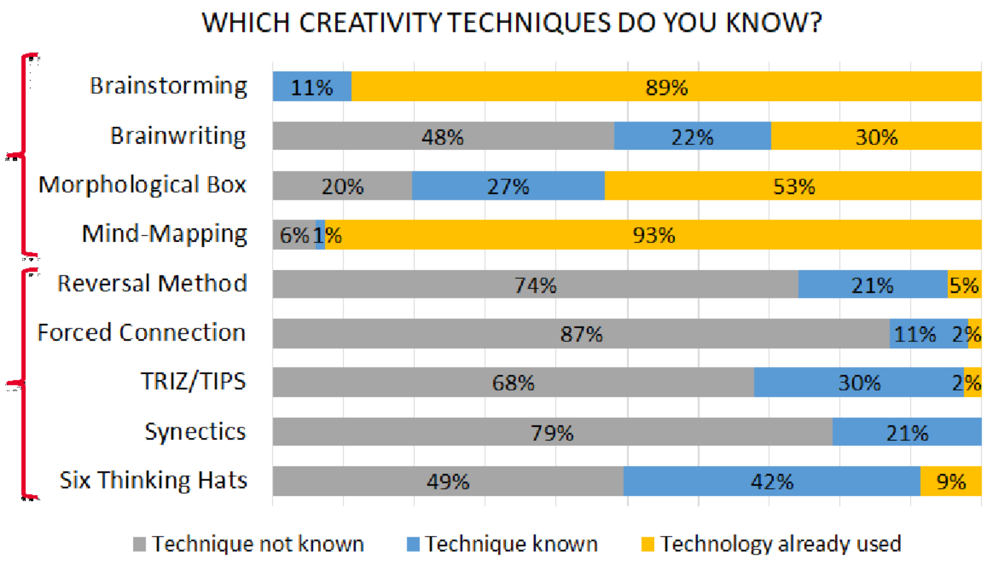

Figure 2: *Familiarity with Creativity Techniques (Survey in Master course "Innovation & Technology Management" (HSD), 2019-2022, n = 81)*

The main result is that our students are usually familiar with creativity techniques that use the heuristic principle of generating alternatives such as the intuitive techniques of brainstorming and mind mapping and the discursive technique of morphological box. The latter is often part of the subjects on theory of design in the Bachelor study program. Our students have almost no experience with creativity techniques that use the heuristic principle of challenging assumptions such as forced connection or TRIZ.

Thus, the familiarity with techniques from the category "generation of alternatives" is much stronger than the familiarity with techniques from the category "challenging assumptions". This fact also seems to drive the choice and evaluation of different creativity techniques by our students, as techniques using "generation of alternatives" are usually preferred over techniques using "challenging assumptions". This tendency to us is worrying, as it leads to a methodological monoculture in engineering and some major creative breakthroughs in the past were achieved by breaking previously unquestioned assumptions.

4 What enables our students to be more creative?

To answer the question what enables our students to be creative we analyzed the results of our Master course "Innovation & Technology Management" during the summer term of 2019. The students worked in groups of five on the task to redesign an everyday object. They could choose their own mess and define their own problem, as long as it dealt with the improvement of everyday objects such as umbrellas, cooking pots or shampoo bottles. In ideation they could choose between intuitive, discursive or heuristic methods or a mix of methods. As intuitive techniques the students chose mostly brainstorming, but some also chose brainwriting, method 6-3-5 or mind mapping. As a discursive technique only the morphological box was used which many students already know due to theory of design from their Bachelor study program. As heuristics the SCAMPER checklist, the heuristic principles of TRIZ and a collection of inventive heuristics collected by the lecturer were used. As a method we used a questionnaire for the students' self-assessment and also an external assessment of the results by experts (Deckert & Mohya, 2020a).

The self-assessment of the students showed that overall intuitive creativity techniques get the highest ratings by students, and most students think that they and their team are more creative using those techniques. Discursive techniques rank highest in the category "ease of use" probably because students already know those techniques from their Bachelor programs (e.g. from theory of design) and those techniques support their systematic-analytical way of thinking. Creative heuristics have the highest rating when it comes to increasing the understanding of creativity (Deckert & Mohya, 2020a).

For the external assessment we used the Consensual Assessment Technique (CAT). CAT is a powerful method to evaluate creative output and is based on the assumption that a product is creative when a panel of experts in a domain independently rates it as creative (Hennessey, Amabile & Mueller, 2011). It can be considered the "gold standard" of creativity assessment (Baer & McKool, 2009). In this case we chose five professors and research assistants from the field of product development and innovation management of Hochschule Düsseldorf, University of Applied Sciences as experts. The result of the rating can be seen in table 1. The ranking shows that a combination of creativity techniques from different categories seems to be most conducive to creativity. Especially the combination of intuitive techniques with either discursive or heuristic techniques seems to be effective while the intuitive technique is usually used before the other techniques. The three groups with the lowest rating all exclusively used intuitive techniques. As the students could chose the techniques and the sequence of application on their own, not all combinations could be tested. It should also be noted that due to the low number of groups the result is not statistically significant, so further research is needed (Deckert & Mohya, 2020a).

Table 1: *Rating of students' results in Master course "Innovation & Technology Management" in 2019 using Consensual Assessment Technique (CAT) (Deckert & Mohya, 2020a)*

Ranking	Group	Rating (% of maximum score)	Applied creativity techniques or heuristics
1	Gr. 7	80	intuitive & discursive
2	Gr. 2	77	intuitive & heuristic
3	Gr. 8	71	intuitive & discursive
4	Gr. 6	60	intuitive & discursive
5	Gr. 4	57	intuitive & heuristic
6	Gr. 1	54	intuitive
7	Gr. 5	49	intuitive
8	Gr. 3	46	intuitive

5 What changes are there due to remote work?

Creativity techniques in an ideation process usually require visualization tools such as whiteboards, presentation boards or flip charts. With these tools people can share their ideas using markers, cards and post-its. Similarly in a virtual workspace, visualization tools such as digital or virtual whiteboards are necessary where remote members can use virtual markers or digital post-its to share their ideas. Virtual whiteboards support teams in capturing, sorting, developing and evaluating ideas through different templates and functions. Furthermore these tools enable teams to document results in various formats and to remotely communicate during ideation sessions. An assessment of ten virtual whiteboards shows that there are simple tools to start with and comprehensive tools offering the whole range of functionality and that companies offering virtual whiteboards continually update their templates and functions (Deckert, Mohya & Suntharalingam 2021).

First experiences with teaching creative problem solving in a virtual environment have been made in the context of the Master course "Innovation and Technology Management" at the Hochschule Düsseldorf, University of Applied Sciences in the summer terms of 2020 to 2022. The students were exclusively taught via MS Teams in the terms of 2020-21 using the Miro board as a visualization tool for ideation, and a combination of online and offline ideation sessions in the term of 2022 using both traditional visualization tools and the Miro board. The main creativity technique used was brain writing. At the end of the term the students took a survey of several questions. The results of the survey are shown in fig. 3.

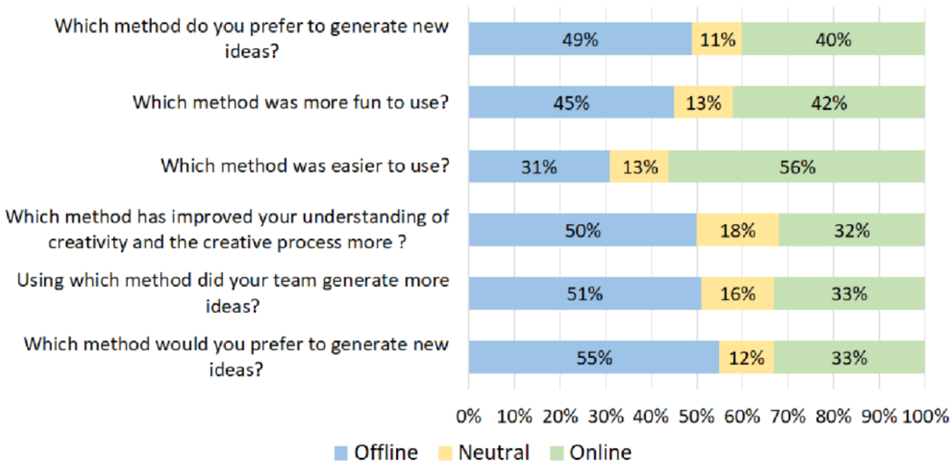

Figure 3: *Comparison of Online and Offline Brainwriting (Survey in Master course "Innovation & Technology Management" in 2021-22, n = 40)*

Fig. 3 shows that our students prefer offline brainwriting to online brainwriting – during the course (question 1) and also in the future (question 6). The main advantages of offline brainwriting are that students generate more ideas, get an improved understanding of creativity and have more fun using the technique. The only category in which online brainwriting leads is "ease of use". This is probably due to the low effort in designing and documenting a board and the comfort of working from home. However, the results are preliminary and still somewhat inconclusive, as students still struggle with the new tools.

6 Conclusions

We draw the following conclusions and further research questions from our research so far:

1. Engineering can be understood as a way of creative problem solving with a focus on functionality. Engineers are creative problem-solvers and drivers for innovation in their organizations.
2. Creativity is only sporadically taught to prospective engineers at German universities. Do we expect "innovation without creativity" from our engineers?
3. Students in our Master program mainly know creativity techniques using generation of alternatives as an idea-generating principle (e.g. brainstorming). What about challenging assumptions? Or heuristics?
4. A mix of different types of creativity techniques seems to be successful for functional creativity. What mix of techniques works especially well for functional creativity?
5. We will probably work online more often than before the pandemic, also in creative work. How does this new work environment impact creativity?

As lecturers in the field of creativity in engineering we see the following key takeaways in our research: We should teach prospective engineers a variety of creativity techniques and let them reflect on the advantages and disadvantages of the different techniques, as this enables them to pick and choose the mix of techniques that suits them best and hopefully fits the problem they have. Furthermore, we should teach students in offline as well as online visualization tools, as we still do not understand the impact of virtual whiteboards on creativity very well, but the professional reality will probably force our students to do more and more creative work in a virtual workspace. So in engineering, creativity is about the right techniques and the right tools but in the end it is also a lot about tinkering.

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