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EVALUATION OF CREATIVITY – STRUCTURING SOLUTION IDEAS COMMUNICATED IN GROUPS PERFORMING SOLUTION SEARCH

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1. Introduction

In the technical product development process as in many other daily situations, creativity plays an important role. Particularly in the phase of searching for solution ideas "creative" solution search in groups is recommended to generate new and unobvious solution ideas [Lindemann 2009]. There is a multitude of methods and recommendations to improve the "creative output" in these so-called creativity sessions. However, the term *creativity* remains fuzzy and the evaluation of the influence of differing factors on creativity sessions is controversial. There is no universal definition of creativity, or as Amabile et al. [2010] state: "*Questions of definitions and the experimental paradigms employed are becoming increasingly complex, yet our ability to precisely define what we mean by creativity remains fairly stagnant."* Creativity can be regarded on different levels, from the neurological level to the systems level. One view on creativity is to see it as a characteristic of individuals; another view is to regard the *creativity of products*, as the result of cognitive processes depending mainly on the situation [Amabile et al. 2010].

In this work, we adopt the second view on creativity, because we want to investigate group creativity sessions and the created solution ideas rather than assessing the capacities of the individual participants of these sessions. Figure 1 illustrates this view on the processes in creativity sessions.

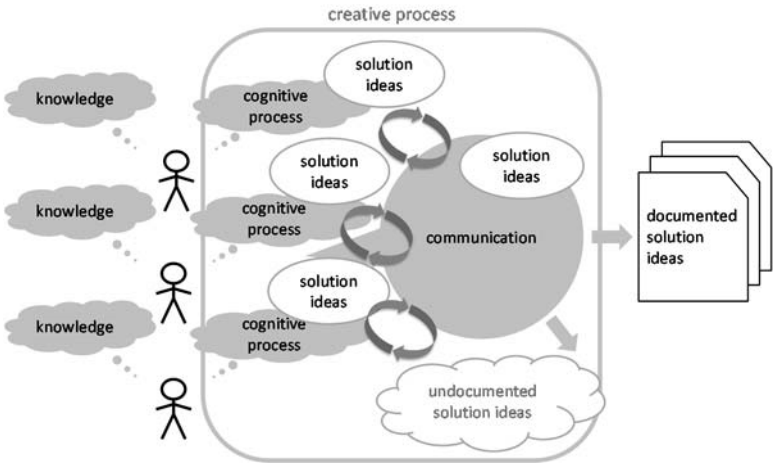

Figure 1. The group creativity process

Based on this model of the group creativity process, the following questions arise: How can group creativity sessions be evaluated? Which elements of the creativity process have to be considered and which of them can be considered? Due to insufficient understanding of the human brain, we cannot evaluate the cognitive processes of the participants. Can the communication be included in an evaluation or is it too complex to assess?
In this paper, we develop an approach to evaluate creativity sessions taking into account the undocumented solution ideas communicated in the creativity sessions in addition to the documented solution ideas. To start with, we give an overview of methods described in literature to evaluate creativity sessions in technical product development. Then we explain how solution ideas can be structured in technical product development. The structuring of solution ideas plays a significant role in the following approach for the evaluation of creativity sessions. The approach is exemplarily assessed by applying it on two creativity sessions.

2. Literature survey

2.1 Evaluation of creativity

According to Amabile et al. [2010] psychologists agree on the two criteria *novelty* and *appropriateness* or *value*. Several authors from the technical product development domain include additional criteria and assess *novelty, variety, quantity and quality* [Shah et al. 2003] or *novelty, variety, quantity and feasibility* [Lopez-Mesa et al. 2006].
Basing the evaluation on the creative process or on the documented solution ideas remains another controversial issue. Cross [2001] reviewed protocol studies of design processes in different areas and identifies *problem framing*, *co-evolution* and *conceptual bridging* as distinctive characteristic related to the generation of creative solution ideas. Shah et al. [2003] argue that the evaluation of the creativity process as a cognitive process is complicated by the fact that cognitive models are based on relatively simple laboratory experiments and not on experiments with technical tasks. Therefore, in technical product development most studies focus on the evaluation of the documented solution ideas, prototypes or products [Shah et al. 2003]. Srinivasan et al. [2010] include utterances of individual designers asked to "*think aloud*" to assess the novelty of concepts at various levels of abstraction.
To allow a comparison between different designers, design groups or different creativity methods, several authors evaluated the generated solution ideas or prototypes with points and applied weights on their different functions or parts [Shah et al. 2003], [Lopez-Mesa et al. 2006], [Venkatamaran et al. 2010]. In the following, the different criteria and the measures are described.

2.1.1 Novelty

A solution idea that is novel for one individual or a group is not necessarily novel to another individual or another group. In fact, novelty can be regarded on different levels. Therefore, Shah et al. [2003] distinguish between *personal, societal and historical* novelty meaning a product or idea that is new to an individual, to one society or to mankind. Srinivasan et al. [2010] considered the third level, *historical* novelty. On every level, the evaluation of a solution idea's novelty is a challenge: It implies the knowledge of all existing solutions novel to an individual, a society or mankind so that the generated solution ideas can be compared to all existing solutions. Authors tackled this challenge with different approaches, either by questioning domain experts [Sarkar et al. 2011], by defining more or less obvious solution ideas [Shah et al. 2003], or by comparing the generated solution ideas or prototypes to one another [Shah et al. 2003], [Lopez-Mesa et al. 2006].
To evaluate novelty, the solution idea can be regarded as an entity or decomposed into its constituent parts. Shah et al. [2003] considered the whole solution idea or prototype with regards to distinct properties. Srinivasan et al. [2010] and Sarkar et al. [2011] divided the solution idea into constructs of the *SAPPhIRE model*, including elements such as parts, functions and physical effects.

2.1.2 Variety

The criterion *variety* is used to measure the differences between the solution ideas generated by one designer or one design group. It indicates how comprehensively the design space, i.e. the theoretical

space of all possible solution ideas is explored. To evaluate the variety of solution ideas, Shah et al. [2003] and Srinivasan et al. [2010] compared the generated solution ideas to each other after decomposing them. Shah et al. [2003] regarded physical principles, working principles and embodiments. Srinivasan et al. [2010] compared additional constructs of the *SAPPhIRE model*.

2.1.3 Quantity

Quantity is a criterion related to *ideational fluency*, the ability to produce a certain number of ideas in a certain amount of time. It is used by a number of researchers as a measure for creativity [Amabile et al. 2010].
Quantity can be evaluated by counting the number of generated solution ideas. Here, it has to be defined how different solution ideas have to be to count separately. Shah et al. [2003] argue that all generated solution ideas can be counted, as the variety criterion evaluates the differences between them.

2.1.4 Quality and usefulness

High *quality* of solution ideas and products is a general goal in technical product development. In the norm DIN EN ISO 9000 [DIN EN ISO 9000 2005] quality is defined as the "*degree to which a set of inherent characteristics*" of a product, process or system "*fulfils requirements*". In mechanical engineering requirements play a significant role in the product development process [Lindemann 2009]. Accordingly, Shah et al. [2003] use *manufacturability*, *minimum weight* and two constraints related to the function of the solution ideas to evaluate the *quality* of solution ideas.
Usefulness is defined by Sarkar et al. [2011] as *social value*, which implies a comprehensive view on a solution idea. It can be defined as a requirement and be related to the *quality* criterion. Sarkar et al. [2011] calculate the *usefulness* by defining a level *of importance* which is multiplied with *popularity, frequency and duration of use* to calculate an overall value for *usefulness*.

2.2 Structuring solution ideas

In technical product development, a common approach for simplifying complex technical tasks is to abstract them as functions. Then, they can be divided into sub-functions and modelled in a hierarchical or network structure. Subsequently, partial solution ideas can be generated for the sub-functions.
There are different approaches to functional modelling. The modelling can be performed on different abstraction levels and have different focusses such as the user, the energy, material and information flow or the relations between useful and harmful functions. Functions can be derived from the overall function or derived from the components of existing products [Lindemann 2009], [Pahl et al. 2007].

3. Proposed approach

The focus of this work is the evaluation of creativity sessions performed in groups for solution search in technical product development. This is based on the assumption that each individual has specific knowledge so that several individuals can generate more or better solution ideas in a group by combining their specific knowledge. Still, groups can also have a negative impact on creativity if interpersonal relations hinder the creativity of group members. As a result of these creativity sessions solution ideas can be documented as conceptual sketches with textual descriptions [Lindemann 2009], [Pahl 2007]. We observed two characteristics of creativity sessions in groups for solution search in which the solution ideas were documented as sketches with textual descriptions:

1. A number of groups generated partial solution ideas instead of overall solution ideas. Even if they developed partial solution ideas to several sub-functions, they seldom integrated them into one or several overall solution ideas. Consequently, they documented a number of partial solution ideas addressing different sub-functions. The degree of completeness of the documented sketches and textual descriptions is therefore heterogeneous. In addition, the degree of detail presented in the sketches and textual descriptions varies from describing a function to describing an existing product as part of their solution idea. This raises the question how the different (partial) solution ideas can be assessed and compared to each other.

2. Many solution ideas discussed during the creativity session were not documented. This can be due to the fact that even if no explicit evaluation of the solution ideas was required in the session, most groups judged on the solution ideas before they started to document them.

These observations raise two questions:

1. How can the partial solution ideas that address different sub-functions with a different degree of completion and different degree of detail be compared to each other?
2. Is it sufficient to evaluate exclusively the documented solution ideas or do we have to additionally consider the undocumented solution ideas to take into account the communication in the creativity process shown in Figure 1?

As described in section 2, a number of existing evaluation approaches in the context of product development focus on documented solution ideas or prototypes [Shah et al. 2003], [Lopez Mesa 2006], [Sarkar 2011]. There are approaches to evaluate the solution ideas individual designers mentioned during the creativity session [Srinivasan 2010]. The group creativity process is observed in protocol studies with regards to cognitive processes [Cross 2001].

In this work an approach is presented that focusses on the evaluation of all communicated solution ideas, both documented and undocumented solution ideas. To meet the varying degrees of completeness and detail of the solution ideas, the approach includes a structuring of the solution ideas.

3.1 Structuring solution ideas

To fulfil the technical task, an overall solution idea addresses the overall function of a technical product. The overall function can be decomposed into sub-functions, which can be solved by partial solution ideas. Inversely, generated solution ideas can be decomposed into partial solution ideas and sub-functions can be derived from these partial solution ideas [Lindemann 2009].

To assess the solution ideas generated in creativity sessions we propose that the person or the group of experts performing the evaluation reviews the solution ideas of different groups, identifies partial solution ideas and deduces their sub-functions. Additionally, other distinct characteristics of the partial solution ideas are used for the structuring. The identified sub-functions and distinct characteristics are used as elements of the structure. Solution ideas generated in the creativity sessions are analysed and assigned to one or to several elements.

After this structuring, measures to evaluate criteria such as *novelty, variety, quantity and quality* can be defined. The criterion *usefulness* can be included in the *quality* criterion as explained in section 2.1.4. In the following sections measures for the four criteria are proposed.

3.1.1 Measures for novelty

In a first step, existing solutions that solve the task of the creativity session, i.e. the overall function, are listed. In order to find as many existing solutions as possible an intensive search in construction catalogues, in patents and on the internet can be performed and experts can be interviewed. The participants of the creativity session do not necessarily know all existing solutions, therefore they can still be personally novel [Shah et al. 2003]. The existing solutions are decomposed into partial solutions and assigned to sub-functions as the generated solution ideas. Consequently, the generated partial solution ideas can be compared to the existing partial solutions. If a generated partial solution idea does not coincide with one of the existing partial solutions, it has some degree of novelty. To evaluate the degree of novelty, the partial solution idea has to be decomposed into its elements, such as its working principle for example. Then the single elements have to be compared to other existing solutions comprising this element. These existing solutions can have different overall functions and have to be detected in addition to the existing solutions with the same overall function.

3.1.2 Measures for variety

The structuring of the generated solution ideas into sub-functions shows if they constitute clusters, i.e. sub-functions that are addressed by more partial solution ideas than others. The *variety* of the solution ideas generated in one or several creativity sessions is evaluated by identifying these clusters. For a more detailed evaluation of the variety, the partial solution ideas addressing the same sub-function can be compared with regard to their elements, such as working principles or embodiment.

3.1.3 Measures for quantity

The *quantity* of the created solution ideas is evaluated by counting. As observed, the generated solution ideas have a different degree of completeness comprising a different number of partial solution ideas. Therefore, the number of partial solution ideas is counted.

3.1.4 Measures for quality

Measures to evaluate *quality* can be derived from requirements as elaborated in section 2.1.4. As the fulfilment of requirements determines the feasibility of a solution idea, quality criteria are crucial for the evaluation. It has to be considered if the quality measures can be applied to all partial solution ideas, or only to partial solutions ideas addressing specific sub-functions.

3.2 Including undocumented solution ideas

To enable the identification of the solution ideas communicated in the creativity sessions, they are recorded with a camera and the spoken conversation is transcripted afterwards. In the protocol, solution ideas are identified. They are decomposed into partial solution ideas and evaluated as the documented solution ideas.

4. Exemplary assessment of the approach by applying it on creativity sessions

The aim of an evaluation of creativity sessions can be to evaluate a specific factor in which these design sessions differ. This factor can be the composition of the group performing the creativity session or the creativity method used by the group, for example. Therefore, in this work the proposed approach is assessed by exemplarily applying it on creativity sessions differing in the factor *composition of the group*. It can then be detected if the differences of the creativity sessions can be captured by the approach.

4.1 Description of creativity sessions

The creativity sessions were performed with groups of two or three people. There were groups composed of three mechanical engineering students, groups consisting of three industrial design students and a group consisting of two mechanics working in a workshop. The task of the creativity session is described by the brief: *design a way that allows people parking and leaving their bike secured*.

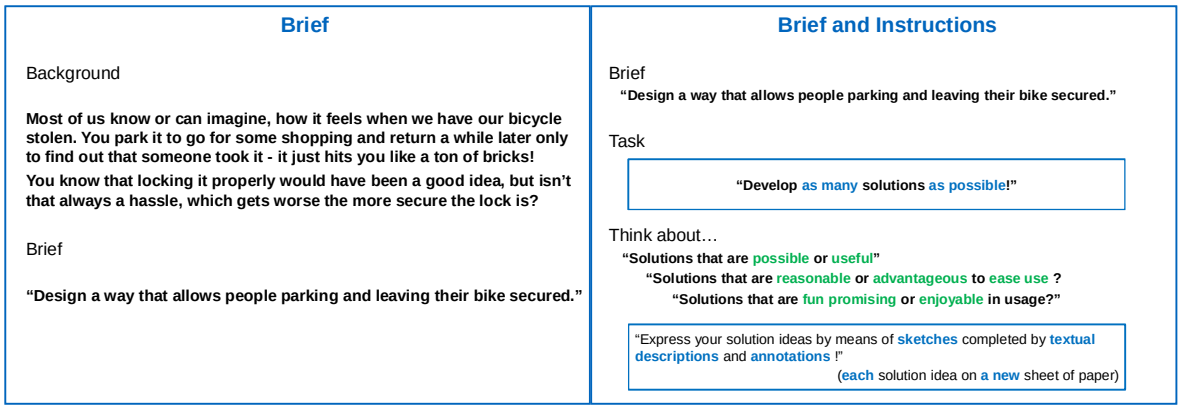

Figure 2. Task of the creativity session

This broad formulation was chosen to give the groups a broad space for generating creative solution ideas. The slides shown in Figure 2 were shown and read out to all groups. The brief and the instructions on the right side of Figure 2 remained visible during the creativity session. No explicit requirements were given to the groups so that they did not have to spent time on understanding and discussing them. Instead, the three points to *think about* hint at requirements. In contrast to requirements they were not obligatory. The groups were asked to sketch their solution ideas and to

complete them by textual descriptions and annotations. After the introduction and the reading of the task, the duration of the creativity sessions was 30 minutes. They were filmed with a camera to document the verbal communication. After 30 minutes the groups were asked to show all the solution ideas they generated and to explain them to the camera. The explanation was later used for a better understanding of the sketches and the textual descriptions of the solution ideas.

4.2 Evaluation of process and results

After the design sessions, the solution ideas of all groups documented in sketches and text were reviewed by the authors. To improve the understanding of the sketches, the filmed presentations of the documented solution ideas were shown. The protocols of the creativity sessions were not used at this stage because of the high number of undocumented solution ideas. The overview over the solution ideas and consequently the structuring becomes difficult if they are included. Analysing the solution ideas confirmed the hypothesis that the majority of the solution ideas are not complete, but they are partial solution ideas addressing different aspects of the design task. Based on the overview of the solution ideas, the structure shown in Figure 3 and Figure 4 and its elements numbered with the letters a to i were developed in a discussion of the authors as explained in section 3.1.

4.2.1 Structuring the solution ideas

The structure contains the four main elements, *protecting the bike*, *activating and deactivating the protective mechanism*, *storing the protective mechanism* and *offering an infra-structural solution*. It is emphasized that these elements are not part of one functional model for the task *parking and leaving the bike secured*. Instead, they represent alternatives to solve the task and are therefore sometimes redundant. The solution idea *lockable bike racks,* for example, addresses the element *offering an infra-structural solution*. Furthermore it includes a partial solution idea for the element *protecting the bike*. It does not have to address the element *storing the protective mechanism*, because the *protective mechanism* is provided in the bike racks, so that the cyclist does not carry it with him or her.
The element *protecting the bike* was further divided into *making the bike undesirable*, *preventing theft* and *complicating the stealing process*. Partial solution ideas belonging to these elements can further be structured. As to the element preventing theft for example, partial solution ideas can be differentiated into partial solution ideas which *lock the bike to something* or partial solution ideas that address *other* sub-functions. In case of the element *activating and deactivating the protective mechanism*, it could not be divided into elements according to sub-functions. Still, the partial solution ideas addressing it show a significant difference: either the (de) activating mechanism is person-inherent such as a code, the use of voice or fingerprints, or it is a tool such as a key card, a chip or a key. Therefore, these distinct characteristics were used as elements. In a next step, all solution ideas were analysed and assigned to one or several elements of the structure. This was done with the documented as well as with the undocumented solution ideas of the groups. For the undocumented solution ideas protocols of the verbal conversations were used to analyse all ideas and solution ideas that were communicated.

4.2.2 Assigning the documented and undocumented solution ideas to elements of the structure

In this paper, the further evaluation is exemplarily shown for one group consisting of mechanical engineering students and for the group of mechanics. Table 1 shows a short description of the documented solution ideas. Table 2 includes a short description of all the undocumented solution ideas taken from the protocol of the creativity sessions. In the tables, the partial solution ideas are assigned to one element of the structure. For example, the first documented solution idea of group A, *cable lock*, comprises both a partial solution idea for *locking the bike to something* (element d) and for *locking the bike in itself* (element f). If a partial solution idea of an undocumented solution idea is among the documented solution ideas it was not additionally assigned to an element as an undocumented solution idea. This is the case for *(un)locking axes with a key card* (group A) which is divided into *(un)locking the axis* as a partial solution idea for *locking the bike in itself* (assignment) and *key card* as a partial solution idea for a *tool activating the protective mechanism* (no additional assignment).

Table 1. Documented solution ideas from group A and group B

group A: mechanical engineering students			group B: mechanics		
(partial) solution idea	**novel?**	**element**	**(partial) solution idea**	**novel?**	**element**
cable lock	no	d, f	foldable lock fixed to the saddle tube	yes	d, j
chain lock	no	d, f	extendable cable lock stored in a box fixed on the bike	no	d, f, j
framed lock	no	d, f	motor bike lock (blocking the handle bar)	no	f
bike lift	no	a, g	alarm system that is actuated when the bike has been moved a certain distance	no	g
spoke lock	no	f	spring lock fixing the rear wheel	no	f
lockable bike racks	yes	d, k			
chip card	no	i			
I-phone application	no	i			
key	no	i			
GPS	no	g			
key card	no	i			
finger print	yes	h			

Table 2. Undocumented solution ideas from group A and group B

group A: mechanical engineering students			group B: mechanics		
(partial) solution idea	**novel?**	**element)**	**(partial) solution idea**	**novel?**	**element**
dismounting bike parts	no	c	“electric shock” device	yes	e
(un)locking axes with a key card	no	f	bike lockers	yes	k
camera on the parking ground	no	g, k	bike rack locking the bikes with spikes	yes	k
camera integrated in the bike	yes	g	wheel clamp	yes	f
setting electric current to the handle bar via remote control	yes	e	fixing the front wheel to the bike’s frame	yes	f
an electric current is switched on when the bike is moved	yes	e	cable lock stored on a cable drum fixed on the bike	yes	j
motion sensor	yes	g	foldable bike (to be folded around poles)	yes	j
spoke lock consisting of titan	yes	f	hydraulic fixing brake	yes	f
spoke lock consisting of carbon fibre	yes	f	“key locking” for the disc brake	yes	f
spoke lock consisting of Teflon	yes	f	foldable lock with a numerical code	no	h
spoke lock (de)actuated by a motor	yes	f	electric key	no	i
			dismounting the handlebar	yes	c
			electro magnet (deactivating with a code)	yes	d
			alarm system that is actuated when the bike is touched	no	e

For a better overview, we visualize the structuring of the solution ideas for both group A in Figure 3 and for group B in Figure 4. The number of solution ideas for each element is depicted in the figures. This visualization was used for evaluating the criteria *novelty*, *variety*, *quantity* and *quality*.

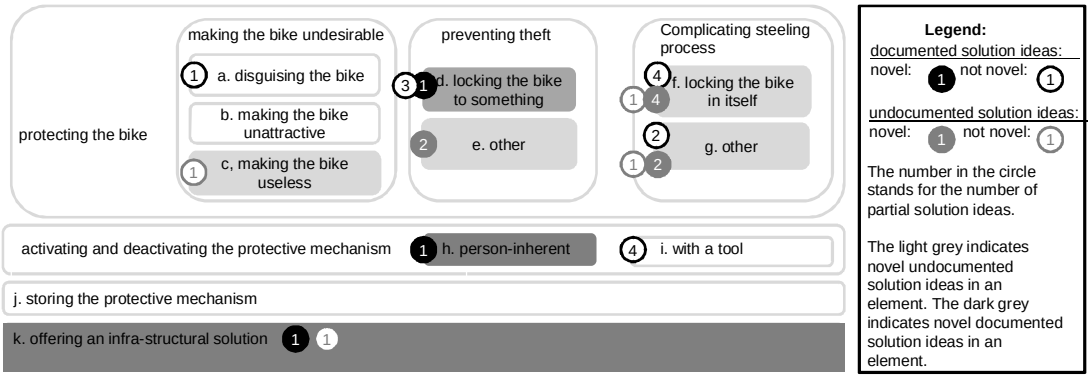

Figure 3. Group A – mechanical engineering students

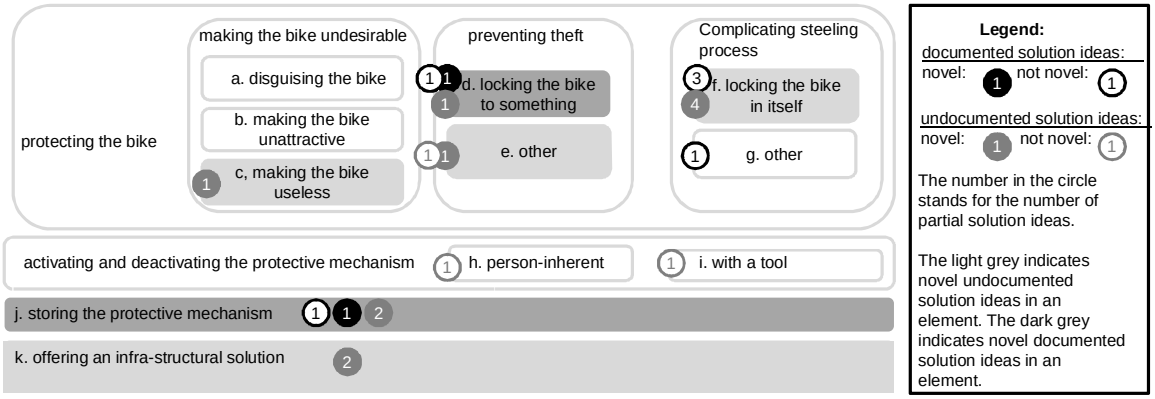

Figure 4. Group B – mechanics working in a workshop of the university

4.2.3 Measures for novelty

As described in section 3.1.1, a list of existing solutions was compiled. It is mainly based on a research on the internet and on patent databases with additions from the authors performing the evaluation. At this stage, exclusively solutions for bikes were used. For example, one partial solution idea of group A, the finger print sensor, exists for actuating a lock, but it was not found for actuating a bike lock. Consequently, using it for a bike lock has some degree of novelty. A more specific evaluation of the degree of novelty can be performed in a later step as described in section 3.1.1. In the following, partial solution ideas with some degree of novelty are called "novel". In the next step, the existing solutions were decomposed into partial solutions and assigned to one or several elements. Then, the partial solution ideas developed by group A and group B were compared to the existing partial solutions. In Figure 3 and Figure 4 the number of novel partial solution ideas is highlighted. Figure 3 shows that group A generated eleven novel partial solution ideas of which they documented three. Group B developed thirteen novel partial solution ideas, documenting two of them. This shows that both groups had significantly more ideas for novel partial solution ideas than presented in the results. Another observation illustrated in the figures is that the two groups generated novel partial solution ideas in different elements of the structure. There are five elements in which both groups generated novel partial solution ideas and three in which only one of them developed novel partial solution ideas.

4.2.4 Measures for variety

Figure 3 and Figure 4 show the number of partial solution ideas the two groups developed per element. This visualization depicts clusters and highlights the elements for which a group did not develop partial solution ideas. Group A, for example did not develop a partial solution idea for the element

storing the protective mechanism whereas group B generated five partial solution ideas for that element. Group A focussed on *activating and deactivating the protective mechanism*. Both groups developed the highest number of partial solution ideas for the element *locking the bike in itself*. Still, among their documented partial solution ideas there is no new partial solution idea in that element.

4.2.5 Measures for quantity

Group A generated 29 partial solution ideas and documented 17 partial solution ideas. Group B developed 22 partial solution ideas and documented eight partial solution ideas which are roughly half of the partial solution ideas documented by group A. To conclude, both groups generated a similar number of partial solution ideas, but group B documented significantly less partial solution ideas compared to group A.

4.2.6 Measures for quality

After the structuring of the partial solution ideas, measures for *quality* can be applied. As described in section 3.1.4 some measures can be applicable on partial solution ideas in one element of the structure or on partial solution ideas in several elements. An example is the criterion *fast actuation of the protective mechanism*. It was derived from the brief given to the groups, where they are asked to think about solution ideas to *ease use*. This measure can be applied on partial solution ideas from the element *activating and deactivating the protective mechanism*. *Ease Use* is formulated more concretely as *number of steps for the (de)actuation*. Group B generated two partial solution ideas in that cluster: *numerical code* and *electric key*. As a *numerical code* has to consist of several numbers so that the right code cannot be guessed by a thief, several steps are necessary to activate and deactivate the lock. The *electric key* can be activated and deactivated by pushing one button. In comparison, the electric key fulfils the criterion *fast actuation of the protective mechanism* better than a numerical code. Accordingly, the partial solution ideas of group A can be evaluated and compared to group B's partial solution ideas.

4.3 Comparison of the two creativity sessions

In order to evaluate the impact of the differing factor, in this case the composition of the groups, the creativity sessions were compared. The approach provides the following findings:

- The measures for *novelty* and *variety* show that the two groups generated *novel* partial solution ideas in different elements of the structure.
- As to the *quantity*, both groups generated a similar number of partial solution ideas, but group B documented about 50 % less partial solution ideas than group A.
- Concerning the *quality* of the solution ideas, the structure allowed for setting up *quality* criteria for specific elements, so that partial solution ideas can be compared in detail.

5. Discussion

Several observations were made during the exemplary application of the approach:
The structure has to be developed according to the focus of the evaluation. The number of elements depends on how precisely the solution ideas will be evaluated. Consequently, the sub-functions have a different degree of abstraction and specific characteristics are used as elements. The inclusion of the undocumented partial solution ideas showed that there were more *novel* undocumented solution ideas than documented solution ideas. A next step can be to analyse why the groups did not document these solution ideas. More investigations have to be done to detect if this is due to their lack of *quality*. At a first glance, this does not seem to be the case. An additional observation was made as to the assessment of *novelty*. It is challenging to define the *historical, societal* and *personal novelty* described by Shah et. al. [2003]. This is due to the fact that a number of solution ideas to a given design task exist in the form of existing products, patents, prototypes. Still, many of these solution ideas, particularly patents and prototypes, are not commonly known because they are not available as products. To assess if the participants are aware of them, they can be asked to list all known solutions.

6. Conclusion and outlook

In solution search during the product development process, groups perform creativity sessions to generate new and unexpected solution ideas [Lindemann 2009]. In this work, we hypothesised that a number of the generated solution ideas are partial solution ideas and that they are not necessarily documented. This raised the questions if it is useful to take into account firstly partial and secondly the undocumented solution ideas for an adequate evaluation of the creativity sessions.

To answer both questions, we developed an approach that is based on decomposing a solution idea into partial solution ideas and structuring them. Moreover, we include the undocumented solution ideas into the evaluation. The approach is exemplarily applied on two creativity sessions which differ in the composition of the participating groups. The exemplary application indicates its usefulness for the evaluation of the creativity criteria *novelty*, *variety*, *quantity* and *quality*. In a subsequent comparison of the two creativity sessions, differences can be assessed by following the approach.

Therefore both questions can be answered positively - it is useful to consider partial and undocumented solution ideas in an evaluation of creativity sessions with the proposed approach.

This work discloses a number of starting points for future research. Creativity sessions differing in factors such as the composition of the group or the use of a creativity method can be evaluated and compared. The evaluation results can serve as an indication for methods and tools that can successfully support the creativity sessions.

To refine the proposed approach, a next step is to detail the measures for the criteria *novelty*, *variety*, *quantity* and *quality*. In addition, the communication process in the creativity sessions can be analysed to study its effect on the creativity of solution ideas. Possible focuses are reasons for a groups' focus of specific partial solution ideas or reasons for not documenting certain solution ideas.

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