

# **INFLUENCE OF COMMUNICATION ELEMENTS AND COGNITIVE EFFECTS ON CREATIVE SOLUTION SEARCH IN GROUPS**

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## **ABSTRACT**

Creative solution search in groups represents a challenge in technical product development. A number of methods and recommendations exist for creativity sessions in groups. However, the influences of these methods and recommendations on the creative process in groups are controversially discussed. In order to enable a comparison of different groups, methods and recommendations for creative search, a better understanding of the creative process is necessary. Therefore, we develop an approach to analyse the influence of communication elements and cognitive effects on the creative process. The approach facilitates regarding the generation, further development and documentation or abandonment of each solution idea communicated in the creativity session. The entire creative process of a group can be analysed quantitatively and compared to several groups. By this means, influences of communication elements and cognitive effects on different performances in creativity sessions are deduced.

*Keywords: creative process, solution search, communication, cognition*

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# 1 INTRODUCTION

“Nothing is more dangerous than an idea when it is the only one you have.” (Émile Chartier)

This quote from the French philosopher can be applied on technical product development, since companies often implement single solution ideas hastily instead of developing alternative solution ideas and choosing the most adequate (Lindemann, 2009). Therefore, the creative search for new, unknown solution ideas represents a central element of the product development process (Lindemann 2009; Pahl et al., 2007). Accordingly, there are a number of methods and recommendations for the phase of creative solution search. One of these recommendations is to perform the creative solution search in group creativity sessions (Lindemann, 2009; Nijstad & Stroebe, 2006; Pahl et al., 2007). Methods such as brainstorming, method 3-6-5 or the gallery method focus on groups. However, their effects are controversially discussed: For example, Nijstad and Stroebe (2006) found that brainstorming in groups produced less solution ideas than individual solution search.

To enable the comparison of different groups, methods and recommendations for creative solution search, researchers from psychology and from technical product development have developed evaluation methods.

For the evaluation of the outcome of group creativity sessions, i.e. the documented solution ideas or prototypes, psychologists agree on using criteria for novelty and appropriateness or value (Amabile and Hennessey, 2010). Researchers from technical product development extend these criteria and evaluate novelty, variety, quantity and quality, usefulness or feasibility (Lopez-Mesa and Vidal, 2006; Sarkar and Chakrabarti, 2011; Shah and Vargas-Hernandez 2003).

In addition to the outcome, the communication process of group creativity sessions can be regarded. According to Stempfle and Badke-Schaub (2002) it “provides a prime access to the thinking and problem-solving process of the design team”. Thus, communication and its relation to cognitive processes can be the key to analyse and understand the effects of different groups, methods and recommendations in detail. In this work, we adopt this view and regard the process of group creativity sessions for (technical) solution search as illustrated in Figure 1:

On the cognitive level, the individual participants develop individual solution ideas. They can communicate their solution ideas to the group in the communication process. The communication process can be divided into communication elements. The communication can provoke cognitive effects which influence the individual development of solution ideas. As the outcome of the creativity session, the solution ideas are documented or abandoned. Consequently, the development of solution ideas can be divided into three phases: Firstly, the solution idea is generated by an individual participant and communicated to the group. Secondly, the solution idea can be further developed, i.e. it is modified by the participants and the modified solution ideas are communicated. Thirdly, the solution idea is either abandoned or documented by the group.

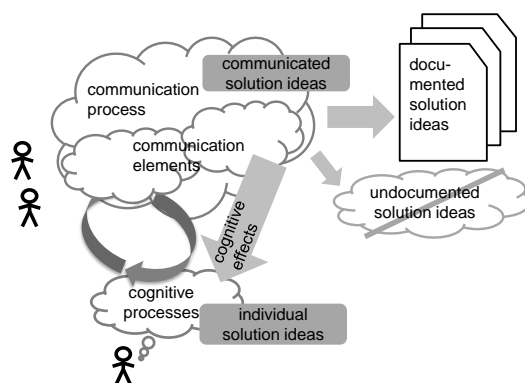


Figure 1: Generation, development, documentation or abandonment of solution ideas in group creativity sessions

In previous work, we have analysed the relationship between communication elements and the cognitive effects *production blocking*, *social loafing* and *social inhibition* (Hashemi Farzaneh et al. 2012b). The aim of this work is to analyse the influence of communication elements and cognitive effects on the generation, further development and documentation or abandonment of solution ideas.

To start with, we give an overview on literature on cognitive effects and assign them to the phases *generation*, (further) *development* and *documentation or abandonment* of solution ideas. In the next step, we develop an approach to analyse the influence of communication elements and cognitive effects on creative solution search in groups. Then we analyse protocols of verbal communication from a design experiment performed with two groups consisting of mechanical engineering students. We regard the influence of communication elements and cognitive effects on the generation, development and documentation or abandonment of all communicated solution ideas. In conclusion, we show the prevalent influences for each group. The approach enables a comparison between the two groups and can be used to compare different groups, methods and recommendations for group creativity sessions.

## **2 LITERATURE SURVEY: COGNITIVE EFFECTS**

By the term *cognitive effects* we summarize processes or effects originated in the environment of individuals (e.g. the group performing a creativity session) which influence the cognitive processes. A number of cognitive effects have been identified in research which can have a positive or negative impact on the generation, development and documentation or abandonment of a solution idea. For example, psychologists have identified a number of effects which reduce the number of ideas generated in group brainstorming (Nijstad and Stroebe, 2006). We give an overview on positive and negative cognitive effects from psychology and technical product development literature. We assign the cognitive effects from literature to one of the three phases *generation*, (further) *development* and *documentation or abandonment* of a solution idea. An overview of the cognitive effects is shown by Table 2.

### **2.1 Generation of solution ideas**

In cognitive psychology, researchers study the cognitive processes of individuals for problem solving. The generation of solution ideas can be regarded as a type of problem solving, as the aim is a solution to a task or a problem. One of the cognitive effects positive for problem solving is *difference reduction*, i.e. the reduction of the difference between the current state and the goal state (Anderson, 2009). For example, if the problem is to “commute to our workplace from home”, the difference between the current and the goal state is the distance. We can overcome this distance by using our car. In case of solution ideas, the identification of the difference between the current and the goal state can trigger the generation of a solution idea.

The *means-ends analysis* adds subgoals to the difference reduction (Anderson, 2009). For example, if we want to solve the problem to “commute to our workplace from home” and our car is broken, a subgoal can be to repair the car. Transferred to solution ideas, the division of the overall goal into subgoals can induce the generation of solution ideas.

*Analogy formation*, i.e. the transfer of solutions from one case to another, has been regarded in cognitive psychology (Anderson, 2009) and in technical product development (Lopez et al., 2011, Srinivasan et al., 2013). Lopez et al. (2012) observed in studies with engineering students that analogies from distant domains result in more creative solutions. Analogies from distant domains are explicitly used in methods for solution search such as biomimetics, which are aimed at the transfer of solutions from nature to the technical domain for the generation of solution ideas (Nachtigall, 2002). In this work, when regarding *analogy formation*, we therefore refer to analogies from distant domains.

As negative cognitive effects, researchers have identified *social inhibition* (also called *evaluation apprehension*) (Diehl & Stroebe, 1987). It describes the fear of the participants that their idea will be considered unfavourably by the other participants. Individual participants affected by social inhibition can be prevented to communicate solution ideas.

Another negative cognitive effect for the generation of solution ideas is *social loafing* (also called *free riding*). It explains the reduced effort of participants of group creativity sessions to generate ideas because the individual participant is not held responsible for the creative output of the group (Diehl & Stroebe, 1987).

*Social matching* is the adaption to the least productive participant of the group creativity session and has the same negative effect on the generation of ideas (Nijstad and Stroebe, 2006).

The cognitive effect *production blocking* occurs in group creativity sessions; because the participants cannot communicate their idea at the moment they generate it. Instead, they have to wait for an opportunity to speak and are distracted by other participants’ ideas (Diehl & Stroebe, 1987). Nijstad and Stroebe (2006) explain *production blocking* by the theory that only one idea at a time can be

processed in the individual participant's working memory which is "forgotten" as soon as he or she is distracted by another idea.

## **2.2 Development of solution ideas**

In product development, Dorst and Cross (2001) analysed protocol studies with industrial designers. The designers parallelly developed the problem and the solution ideas during their design process. This *co-evolution of problem and solution ideas* triggers the further development of solution ideas.

As a negative cognitive effect for the development of solution ideas, Jansson and Smith (1991) name *fixation*, the attachment of individuals to previously generated ideas. Cross (2001) differentiates between fixation to *existing designs* and *attachment to concepts* that have been previously developed. In case of *fixation to existing designs*, an individual participant of group creativity sessions generate and communicate an existing solution idea which is familiar to one or several participants. This can prevent the further development and improvement of solution ideas. *Attachment to concepts* has the same effect, but in this case, the solution idea is a concept initially generated in the design process. A number of studies show that participants often do not question these initial concepts (Cross, 2001).

## **2.3 Documentation or abandonment of solution ideas**

In design experiments with groups of mechanical engineering students, industrial design students and mechanics, the groups did not document a significant number of solution ideas even though they had been instructed to document all solution ideas (Hashemi Farzaneh et al. 2012a). We observed that the groups implicitly or explicitly (see section 3) decided for or against the documentation of a solution idea. Cognitive effects that can influence the decision for the documentation of a solution idea either positively or negatively are *heuristics*. According to Gilovich et al. (2002), decisions under uncertainty are often based on a small number of simplifying heuristics and not on "extensive algorithmic processing". An example for a *heuristic* is the *availability heuristic* – judging based on the information which can be retrieved easily from memory (Hallihan et al., 2012). In psychology, an increasing number of heuristics have been studied (Gilovich et al., 2002). For product development, Hallihan et al. (2012) lists ten "relevant" heuristics. All heuristics support a quick decision, which can also lead to errors (Gilovich et al., 2002).

*Distraction conflict* is a negative cognitive effect for the attentiveness of an individual (Baron 1986). Similar to production blocking, the participants of group creativity sessions can be distracted by other ideas, and "forget" to document previously generated and developed ideas.

# **3 APPROACH FOR THE ANALYSIS OF THE INFLUENCE OF COMMUNICATION ELEMENTS AND COGNITIVE EFFECTS**

As described in the previous section, studies from psychology and product development indicate that cognitive effects influence the generation, development and documentation or abandonment of ideas.

On the other hand, particularly studies from psychology do not have a technical focus (for example Nijstad and Stroebe 2006). The relevance of the identified cognitive effects for creative solution search in technical product development is therefore not proven. Is it sufficient to consider the cognitive effects for the analysis of group creativity sessions?

In addition, a number of studies are designed to identify one single cognitive effect under laboratory conditions (for example Hallihan et al., 2012). How can we identify several cognitive effects in the communication process of one group creativity session?

Consequently, we focus on the communication in a first step. As depicted in Figure 1, the communication can be divided into communication elements (section 3.1). In a second step, the communication elements are related to cognitive effects so that they can serve as an indication for cognitive effects (section 3.2). Then, we propose an approach to analyse the impact of both the communication elements and cognitive effects on the generation, development and documentation or abandonment of solution ideas (section 3.3).

## **3.1 Dividing communication into communication elements**

Table 1 shows the scheme to divide communication into communication elements which was developed in previous work (see Hashemi Farzaneh et al., 2012). Based on a classification from Stempfle and Badke-Schaub (2002), organisational-related and content-related communication elements were defined. The content-related elements were assigned to the stages of the technical

product development process according to Lindemann (2009). As the focus of the analysis is the search for solution ideas, the communication element *solution idea* was further divided into several communication elements depicted in Table 1 (Hashemi Farzaneh et al., 2012). In this work, the communication element *analogy* is added to identify the cognitive element *analogy formation* (see section 3.2).

Table 1: Communication elements

category	communication element	
organisational-related	planning	
	analysis	
	evaluation	
	decision	
	control	
content-related	goal planning	
	goal analysis	
	task structuring	
	(generation of) solution idea(s)	new category
		variation
		concretization
		expansion of the scope
		repetition
		classification
		<b>analogy</b>
	properties assessment	neutral statements/ questions
		positive statements/ questions
		negative statements/ questions
	decision making	
	ensuring goal achievement	
other	replication	
	jokes and laughter	
	other verbal communication	

### 3.2 Relating communication elements to cognitive effects

Communication elements can serve as indication for cognitive effects. In previous work, the cognitive effects *social inhibition*, *social loafing* and *production blocking* were related to communication elements by analysing protocols from design experiments. As a result, we found that specific communication elements trigger specific cognitive effects, but not in all cases. In consequence, we can use communication as an indication for cognitive effects, but not deduce a causal relationship (Hashemi Farzaneh et al. 2012b). Table 2 shows the proposed relations between communication elements and cognitive effects.

Table 2: Relation between communication elements and cognitive effects

phase	cognitive effect	indicating communication elements
generation of a solution idea	<i>difference reduction</i>	<i>goal planning / goal analysis</i> (before <i>solution idea</i> )
	<i>means-ends analysis</i>	<i>goal planning / goal analysis</i> and <i>task structuring</i> (before <i>solution idea</i> )
	<i>analogy formation</i>	<i>analogy</i> (before <i>solution idea</i> )
	<i>social inhibition</i>	<i>negative statements/ questions</i> or <i>jokes and laughter</i>
	<i>social loafing/ matching</i>	a period of time with no communication elements
	<i>production blocking</i>	high number of <i>new category</i> in a short period of time or alternation between <i>concretization</i> and <i>expansion of the scope</i>
development of a solution idea	<i>co-evolution of problem and solution ideas</i>	alternation of <i>solution idea</i> (all elements) and <i>goal planning/ goal analysis</i>
	<i>fixation to ex. designs attachment to concepts</i>	no <i>solution idea new category/ variation/ expansion of the scope/ analogy</i> (after <i>solution idea</i> )
documentation/ abandonment of a solution idea	<i>heuristics</i>	low number of <i>neu./ pos./ neg. statements/ questions</i> (after <i>solution idea</i> )
	<i>distraction conflict</i>	all communication elements (after <i>solution idea</i> ) except <i>repetition, properties assessment</i> (all elements), <i>decision making, ensuring goal achievement</i>

### 3.3 Analysis of the generation, development and documentation or abandonment of solution ideas

To analyse the influence of communication elements and cognitive effects on the generation, development and documentation or abandonment of solution ideas, we identify all communicated solution ideas of the creativity session. After a fragmentation of the communication protocol into communication elements, all *solution idea* communication elements (except *repetition*) are labelled as a solution idea. Semantic categories are identified as shown in the example in Figure 2:

From solution idea 1.0 to solution idea 2.0 there is a leap between semantic categories, i.e. the two solution ideas have no semantic relationship because they are based on different images in the working memory (Nijstad and Stroebe, 2006, Hashemi Farzaneh et al., 2012). According to Goldschmidt's *linkography* approach (2012), a framework for links between communication elements (called *moves*), the two solution ideas are not linked to each other. Solution ideas 2.0 and 2.1 are separate solution ideas belonging to one semantic category, as solution idea 2.1 is a concretization of solution idea 2.0.

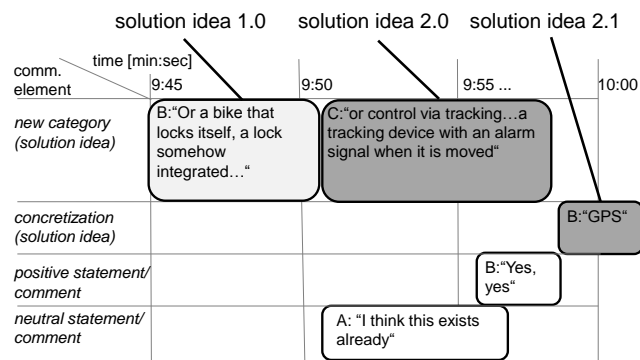


Figure 2: Identification of solution ideas in the communication protocol of a creativity session (A: participant A, B: participant B, C: participant C)

After the identification of all solution ideas, the communication elements preceding and following a solution idea are listed. All communication elements until breaks or new solution ideas are captured. As can be seen in Figure 2, with regards to solution idea 2.0, the preceding communication element is *new category*, the following solution elements are *neutral statement/comment*, *positive statement/comment* and *concretization*. In the next step, cognitive elements indicated by the identified communication elements are assigned using the scheme shown in Table 2.

Then, the three phases *generation*, *development* and *documentation or abandonment* of each solution idea are analysed regarding possibly influencing communication elements and cognitive effects. For each phase they are listed in Table 3. The quantitative analysis of all solution ideas of creativity sessions and the subsequent comparison between several groups allow for conclusions as to the influences of communication elements and cognitive effects on different performances in the generation, development and documentation or abandonment of solution ideas. In section 4 and 5, we use the approach exemplarily on protocols from a design experiment with two groups, compare the results and discuss the conclusions that can be drawn from applying the approach.

Table 3: Analysis of the influences of communication elements and cognitive effects on solution ideas in the generation, development and documentation or abandonment phase

phase	Influencing communication elements and cognitive effects
generation of a solution idea	<ul style="list-style-type: none"> <li>preceding communication elements</li> <li>cognitive effects: <i>difference reduction, means-ends analysis, analogy formation, social inhibition, social loafing and matching, production blocking</i></li> </ul>
development of a solution idea	<ul style="list-style-type: none"> <li>following communication elements, particularly concerning solution ideas of the same semantic category</li> <li>cognitive effects: <i>co-evolution of problem and solution ideas, fixation to existing designs, attachment to concepts</i></li> </ul>
documentation or abandonment of a solution idea	<ul style="list-style-type: none"> <li>following solution elements until the documentation or abandonment of a solution idea (indicated by a leap to other solution ideas for example)</li> <li>cognitive effects: <i>heuristics, distraction conflict</i></li> </ul>

## 4 DESIGN EXPERIMENTS

The design experiment was performed with two groups, each consisting of three different mechanical engineering students who had not worked together before the design experiment. The task was to *design a way that allows people parking and leaving their bike secured*. This broad formulation was chosen to give the groups a broad space for generating creative solution ideas.

No explicit requirements were given to the groups so that they did not have to spent time on understanding and discussing them. Instead, the students were asked to *think about* solutions that are *possible or useful, reasonable or advantageous to ease use* and *promising or enjoyable in usage*. These statements hint at requirements without constraining the task. The groups were asked to sketch their solution ideas and to complete them by textual descriptions and annotations. Except paper and pens, no other auxiliary material was given to the groups. 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 protocol the verbal communication. The complete brief can be taken from Hashemi et al. (2012a).

## 5 RESULTS OF THE ANALYSIS OF THE DESIGN EXPERIMENTS

In this section, we present the results from the quantitative analysis of all solution ideas of the design experiments and compare the two groups. Both groups followed a different proceeding: Group 2 communicated 45 solution ideas, documented 19 of them in a list and drew sketches of 11 solution ideas afterwards. Group 1 communicated 25 solutions, documented 15 of them in a list, evaluated the listed solution ideas (despite having been given no instructions to do so) and drew sketches of 9 of them. Figure 3 depicts the communication elements preceding the generation of solution ideas of group 1 and group 2. Figure 4 shows the *solution idea* communication elements of the two groups.

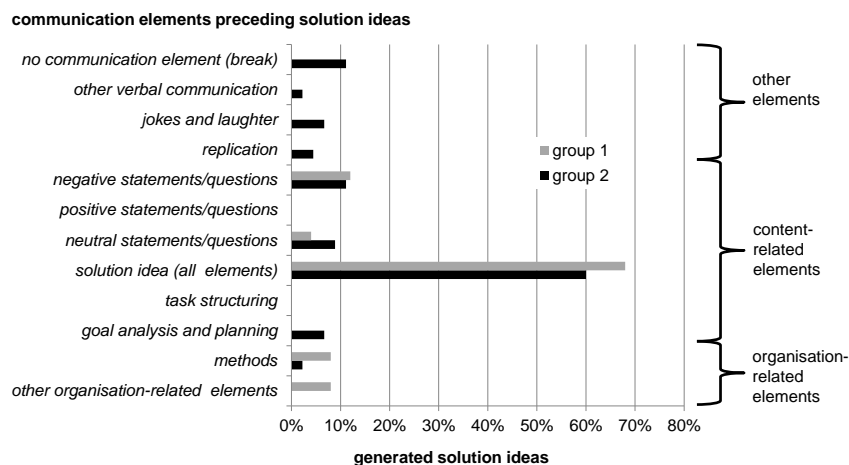


Figure 3: Communication elements preceding the generation of solution ideas

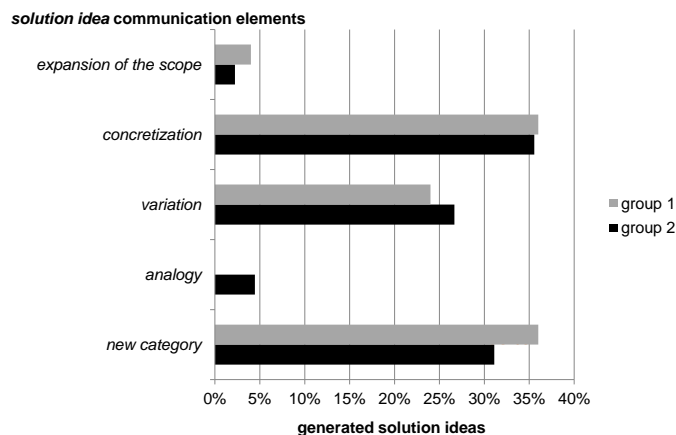


Figure 4: Solution idea communication elements

Figure 5 depicts the communication elements following abandoned solution ideas of group 2, i.e. solution ideas which were neither included in the list nor sketched. The analysis of the communication elements of group 1 does not provide useful insights because of the group's evaluation: During the evaluation the group assigned points for several criteria with little discussion (maximum six utterances per criteria) to the previously listed solution ideas. This indicates the cognitive effect *heuristics*.

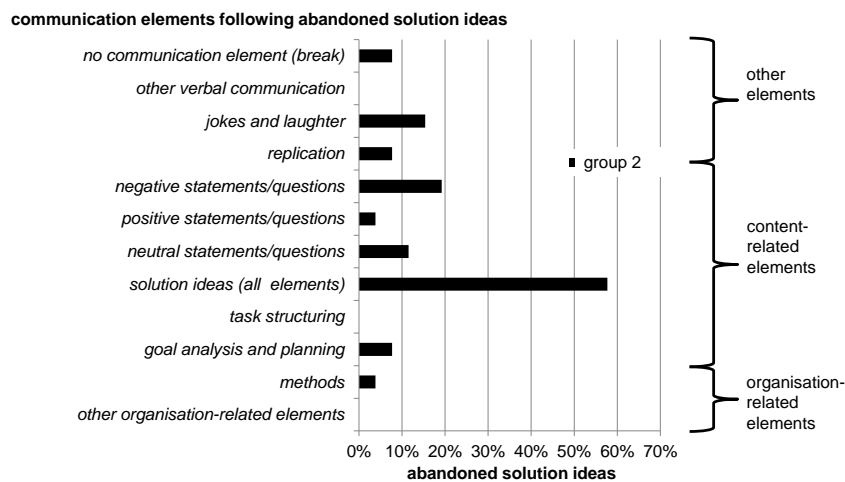


Figure 5: Communication elements following abandoned solution ideas

### 5.1 Generation of solution ideas

As shown in Table 3, the communication elements preceding solution ideas are regarded as to their influence on the generation of solution ideas. As can be seen in Figure 3, both groups generated solution ideas after the communication of other solution ideas (all communication elements).

With regards to positive cognitive effects, there was no indication for difference reduction and means-end analysis, because less than 10 % of the solution ideas were generated after *task structuring* or *goal analysis and planning* communication elements. Figure 4 depicts that no *analogy formation* could be observed; since less than 5 % of the solution ideas belonged to the communication element *analogy*.

As to negative cognitive effects, Figure 5 shows that about 35 % of the abandoned solution ideas of group 2 were followed by *negative statements/ questions* or *jokes and laughter*. This indicates the cognitive effect social inhibition as it can prevent the participant, who has contributed the solution idea, not to communicate other solution ideas. Additionally, indications for social loafing or matching could be found for group 2: Two of the participants took five breaks that lasted longer than 10 seconds while the third participant was sketching. With regards to production blocking, 9 % of solution ideas from group 1 and 12 % of solution ideas from group 2 were followed by the communication element *new category* (not depicted in the figures). This indicates a few cases of *production blocking* of further solution idea generation for both groups.

### 5.2 Development of solution ideas

Figure 4 illustrates that 35 % of the communicated solution ideas of both groups were *concretisations* of solution ideas, about 25 % were *variations* and about 30 % were solution ideas of a *new category*. In consequence, concretisation and variation was the strategy both groups used most for the further development of solution ideas. Regarding the cognitive effect *co-evolution of problem and solution ideas*, 0% of the solution ideas from group 1 and 4 % of the solution ideas from group 2 were followed by the communication elements *goal planning* and *goal analysis*. The fact that about 30 % of the communicated solution ideas were of a new category indicates that there was no *fixation on existing designs* or *attachment to concepts*.

### 5.3 Documentation or abandonment of solution ideas

As can be seen in Figure 5, about 35 % of the abandoned solution ideas of group 2 were followed by *negative statements/ questions* or *jokes and laughter*. This indicates a role of negative criticism for the abandonment of solution ideas. Figure 5 shows that 58 % of the abandoned solution ideas from group 2 were followed by other *solution ideas* (all categories). This fact indicates an occurrence of



distraction conflict: The participants of group did not consciously choose to abandon the solution idea but were distracted by the following solution ideas. With regards to heuristics, 38 % of the documented and abandoned solution ideas of group 2 were followed by statements or questions (not depicted in the figures). Still, the number of communication elements for each of these “evaluations” was maximum four; none of the solution ideas was discussed in more detail. As explained at the beginning of this section, the same observation was made during the evaluation phase of group 1.

## **6 DISCUSSION OF THE RESULTS**

In the previous section, we analysed communication elements for two groups performing a design experiment. From the analysis of the communication element we deduced indications for cognitive effects. However, six of the cognitive effects could not be observed. This can be explained by the type of the design brief and the task:

- Goal analysis and structuring represented less than 5 % of all communication elements. Therefore, no indications for *difference reduction*, *means-end analysis* and *co-evolution of problem and solution ideas* could be observed. This can be due to the task: As the securing of bikes is a well-known problem, the students did not reflect the goals in detail.
- The absence of *analogy formation* can be explained by the design brief which did not encourage the students to use analogies
- The absence of indications for *fixation on existing designs* or *attachment to concepts* can be explained by the design brief’s statement that the groups should “develop as many solutions as possible” (see Hashemi Farzaneh et al. 2012 a)

In order to explore the relations between communication elements and these six cognitive effects, the design experiments can be adapted.

## **7 CONCLUSION AND OUTLOOK**

In this work, we develop an approach for the analysis of the generation, development and documentation or abandonment of solution ideas in protocols of group creativity sessions. The first step of the approach is the fragmentation of communication into communication elements. In the second step, indications of communication elements for cognitive effects are deduced. In the third step, the influence of both communication elements and cognitive effects on the generation, development and documentation or abandonment of solution ideas is regarded. A quantitative analysis of the protocol and a comparison between several groups allow for conclusions as to the influences of communication elements and cognitive effects on different performances of the groups. We use the approach exemplarily on protocols of the same design experiment with two mechanical engineering student groups. The results of both analyses were similar. As the design experiment was the same and the groups consisted of participants with similar background, this indicates the usefulness of the approach.

As described in the previous section, six cognitive effects could not be observed. In future work, the reasons for the absence of these cognitive effects can be used to design further design experiments which stimulate the occurrence of the effects in order to explore the relations between communication elements and the cognitive effects. For example, in order to stimulate the occurrence of analogy formation, an analogy stimulating method such as biomimetics can be suggested to the groups. Ultimately, this approach can serve for an analysis and comparison of different groups, methods and recommendations for creative solution search. This enables a better understanding of different performances in the generation, development and documentation or abandonment of solution ideas. Consequently, groups can be supported more effectively and methods and recommendations for creative search in groups can be adapted to the real needs of the groups.

## **ACKNOWLEDGMENTS**

The authors want to thank the participating students and the colleagues of the Institute of Product Development.

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