Elicitation of Adaptive Requirements
Using Creativity Triggers: A Controlled Experiment

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ABSTRACT
Adaptive systems react to changes in their environment by changing their behavior. Identifying the needed adaptations is central to requirements elicitation for adaptive systems. As the necessary or potential adaptations are usually not obvious to the stakeholders, the problem is how to effectively elicit adaptation-relevant information. One approach is to use creativity techniques to support the systematic identification and elicitation of adaptation requirements. In particular, here, we analyze a set of creativity triggers defined for systematic exploration of potential adaptation requirements. We compare these triggers with brainstorming as a baseline in a controlled experiment with 85 master students. The results indicate that the proposed triggers are suitable for the efficient elicitation of adaptive requirements and that the 15 trigger questions produce significantly more requirements fragments than solo brainstorming.

KEYWORDS
Elicitation, Creativity Trigger, Adaptive Requirements

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1 INTRODUCTION
Systems need to be adaptive to ensure the appropriate functionality in many different situations, while the environment and the system themselves may change. An adaptive system must monitor itself and the environment, which we refer to jointly as situation. Changes in the situation may then trigger adaptations of the system (behavior).

The aim of our research is to improve the systematic development of adaptive systems from a requirements engineering perspective. Thus, we are working on an RE process to derive requirements for adaptive systems with a focus on the early phases. One idea is to systematically analyze different situations to uncover requirements, especially requirements, which are adaptation-relevant.

One challenge for the development of adaptive systems is to understand the triggers for an adaptation, the adaptation itself, and the dynamic behavior of the system. That is, to elicit adaptive requirements. Usually, stakeholders are neither consciously nor unconsciously aware of them. Thus classic elicitation techniques such as interviews or observations are less effective.

Creativity techniques have gained a lot of research interest in the requirements engineering community as a means of exploration [3]. Creativity techniques are used to trigger novel insights during elicitation and identify new requirements and understand non-obvious implications of existing requirements.

As a basis for identification of adaptive requirements our approach relies on 15 trigger questions tailored to the needs of adaptive systems. The use of trigger questions is rather common as a creativity technique (cf. checklist techniques in [12]).

While a plethora of general creativity techniques exist, a central hypothesis of our work is:

(H1) Applying specialized creativity techniques in elicitation of adaptive requirements leads to better results than the use of generic elicitation techniques.

While we do not claim to address the full breadth of this question, our experiment will still shed some light on this.

The main goal of our paper is to compare adaptation-tailored creativity triggers with the generic creativity technique solo brainstorming as a baseline in a controlled experiment. The result of applying a creativity or elicitation technique is a number of requirements fragments, but usually not elaborated requirements. This is taken into account in the following research questions:

RQ1: Is our approach relying on trigger questions more effective regarding the number of collected requirement fragments compared to the baseline?

RQ2: Is our approach perceived as more useful than brainstorming from a user perspective?

RQ3: How effective are the individual trigger questions of AdaptationExplore objectively in terms of collected requirement fragments?

RQ4: What is the individual usefulness of AdaptationExplore trigger questions from a user perspective?

The remainder of the paper is structured as follows. First we give an overview of related work in Section 2. Then we introduce the two techniques used by the participants in Section 3. In Section 4 we discuss the design and materials of our controlled experiment. The results are presented and interpreted in Section 5. The threats to validity relating to our experiment are discussed in Section 6. Finally, we conclude and present some resulting research directions in Section 7.
2 RELATED WORK
There is a significant body of research on elicitation techniques. A systematic review of empirical studies [6] summarizes that semi-structured interviews were found most effective in studies, while other techniques such as thinking aloud tend to be less effective.

More recently creativity techniques came into focus of RE research as they can be successfully applied to elicit requirements. In our work, we focus on lightweight techniques [30], which require less effort for training and application. The following discussion of related work focuses on empirical studies (cases studies and experiments) in this regard.

A number of controlled experiments to collect sound empirical evidence were conducted on EPMCreate [13]. For example, Herrmann et al. compared two variants of this technique regarding the effectiveness in generating requirements ideas and its feasibility [13].

Niknafs et al. [20] empirically investigated the role of domain knowledge in idea generation during requirements elicitation. The authors conducted a controlled experiment that investigates the impact on quantity and quality of generated ideas.

Solis and Ali [28] showed that wikis support the creativity during the elicitation process by supporting the open collaboration between stakeholder, exchange ideas, information, and support versioning and traces of changes.

Oshiro et al. [21] investigated the effect of creativity techniques during the elicitation of goals and sub-goals in goal-oriented requirements engineering. The result shows that the generated ideas directly lead to the identification of high-quality goals. During the grouping of ideas many misunderstandings between stakeholders could be solved.

Sørensen et al. [29] argues for the use of creativity techniques in requirements elicitation. They use creativity workshops to identify requirements and help the stakeholders to understand the vision of the system as well as technology. They noticed that a user who can be creative is fundamental for the usefulness of the requirements.

Pinto et al. [22] performed 6 case studies to test IdeaSy, a tool for elicitation of requirements using combinatorial creativity techniques. The goal of combinatorial creativity is to combine different words to generated new ideas. IdeaSy also supports the elaboration of ideas from different sources like text, videos, pictures, and audio. The results showed that the majority of the requirements produced using IdeaSy were evaluated as original and innovative.

Franco and Giraldo [11] performed an empirical study comparing brainstorming and Creative Requirements Elicitation Assisted by Scenarios method (CREAS). The results showed that CREAS helps to elicit requirements with more quality than brainstorming.

Burnay et al. [5] investigate the influence of creativity triggers on the elicitation of requirements. They identified six new creativity triggers, which guide stakeholders to discover new requirements associated with a particular quality of a product. Entertaining triggers are used to discover fun or captivating features, light triggers to simplify the solution, adaptable triggers to replace multiple products with one adaptable product, economical triggers to reduce the consumption of resources, complete triggers to make a solution more integrated and more comprehensive, and finally, durable triggers to find features that make a solution more durable and long-lasting.

Schmid [27] reported on the benefits of the deconstruction technique and trigger lists as creativity techniques to identify ideas for new product concepts. An interesting result of this industrial case study was that new concepts were discovered in a creativity session although the organization already thought of new concepts for quite some time.

El-Sharkawy et al. [9] provide an approach to support product innovation in RE. They suggest heuristics to derive creative requirements from idea maps. The results of a controlled experiment showed that six heuristics performed significantly better than random stimuli.

Mich [19] suggests a framework to support requirements engineers in choosing creativity techniques for the elicitation of requirements. They noticed that the gap between the provided creativity technique and actually used techniques is wider than expected. The framework provides different means to evaluate whether a technique is suitable for the elicitation process of a given project.

Bottomline is that in particular lightweight approaches to elicit/innovate requirements using creativity techniques have been described and applied in case studies and controlled experiments. However their application to develop requirements for adaptive systems and an empirical evaluation has not been conducted so far to the best of our knowledge.

3 TECHNIQUES
We will now discuss the techniques applied in the experiment. First, we provide some background on the elicitation of adaptive requirements and, in particular, we introduce the notion of a situation. The elicitation technique presented in this section is part of a continuous requirements engineering process called AdaptationExplore developed by Kneer et al. [17].

3.1 Background
We use the term adaptive requirements to denote “requirements that encompass the notion of variability associated to either a functionality or a system quality constraint” as defined by Qureshi and Perini [24]. According to their definition, an adaptive requirement includes a monitoring specification that takes into account the variability in the environment, evaluation criteria and alternative behaviors to be adopted at runtime by the software system.

De Lemos et al. [7] identified challenges for adaptive systems. One of these is the need for a development process for adaptive systems. More precisely, there is a lack of support for the early phases in the development of an adaptive system, which was also recognized by Dey and Lee [8] and Kneer et al. [16].

We introduce in the following the concept of a situation. We believe this to be very useful in supporting the elicitation of adaptive requirements as it helps to deal with the complexity that arises from the real world. Focusing on one situation at a time simplifies this complexity as it slices the problem domain into less complex chunks. We assume this to be beneficial to the systematic elicitation of adaptive requirements by reducing cognitive load.

A situation can be regarded as a special kind of view. Similar to the concept of views, it can be restricted to certain elements (e.g., entities from the real world) or specific kinds of information (e.g., structural vs. behavioral view). In extension to the concept of a view, a situation further restricts the focus to a specific moment in time (or small time interval) and, thus, implies a certain state of the system and its environment. This restricts the behavior and highlights certain entities like environmental entities or stakeholders.
More precisely, we characterize a situation by the structure, function, and behavior of a system and the relevant part of the environment at a particular location over a time period of particular interest. For instance, let us assume a smart street light that adapts to weather conditions, time, and frequency of pedestrians and vehicles. One situation of the smart street light could be an ambulance warning: The rescue center sends a warning to all street lights, which are on the path of an ambulance. Cars and pedestrians along the route will be notified by switching the color of the smart street light to red. Involved environmental entities are cars, pedestrians, ambulance, and rescue centers. Involved system entities of the street light are movement sensor, distance sensor, light (color, intensity). The situation would persist as long as the ambulance is approaching or close by.

We use the notion of a situation as a basis for a creative process for unfolding adaptation scenarios. It is analyzed with the help of AdaptationExplore trigger questions (TQ), which guide the developer to spot missing environmental information, to identify new situations, and potential adaptations.

We employ textual situation descriptions (as the ambulance warning above) and UML models\(^1\) as a basis to apply the creativity techniques illustrated in the following.

### 3.2 AdaptationExplore Trigger Questions

Trigger questions are well-known as a lightweight creativity technique and we used the 5WH (Kipling) technique to systematically derive questions related to the 6 question words (what, where, when, why, who, and how). The result is a set of 15 trigger questions (see Table 1), which should trigger new ideas in the context of an adaptive system and its dynamic environment. The goal of the question set is to identify missing information regarding environment entities, resources, new functionalities, alternative realization of functionalities, and triggers for adaptations (i.e., the ingredients of an adaptive requirement).

The trigger questions are designed to be applied to UML models, that is they are applied to structural models (e.g., class diagrams) and behavioral models (e.g., sequence diagrams). The first four questions are applied to classes, entities, and similar high level objects of a situation. The questions 4 to 12 are related to functions and the effects on the system and its behavior, needed resources, alternative realizations. The last three questions support the analysis of environmental quantities in a situation. They aim at identifying influences, resources, or calculations relevant to an environmental quantity.

The answers to these questions are requirements fragments, which could be, e.g., an idea, an incomplete requirement, a list of functions, or a quality aspect.

A few examples of ideas (requirements fragments) related to the trigger questions in the ambulance warning situation are (Qx refers to the corresponding question in Table 1): Q8: In case the smart street light operates in an energy-efficient mode, an ambulance warning is activated only if there is a strong need due to intense traffic. Q12: High intensity of the light and frequent changes of the intensity should be avoided if species are nearby at particular times (e.g., during mating season). Q14: The lighting conditions could be measured with a color sensor to ensure red is really perceived as red under current conditions.

| Table 1: AdaptationExplore Trigger Questions |
|-----------------------------------------------|
| **High Level Objects**                        |
| (1) What should the model element be related to? |
| (2) Does the model element have missing restrictions? |
| (3) What information could the model element provide for a feature and how could the model element be used by a feature? |
| (4) How should the model element be accessed? |
| **Activity (Functions):**                      |
| (5) On what should the success of the functions depend on? |
| (6) What should the function be related to?    |
| (7) Does the function have missing restrictions? |
| (8) Could there be any obstructions or conflicts due to other functions? |
| (9) What information should the function provide and for what could the information be used? |
| (10) How could the function be accessed?      |
| (11) Could the function fail?                 |
| (12) Could there be any reasons not to perform the function? |
| **Environmental Quantities (Variables):**      |
| (13) What influences the variable?            |
| (14) Where could the value(s) of the variable come from? |
| (15) What is the variable used for?           |

### 3.3 Solo Brainstorming

We selected solo brainstorming as a generic creativity technique, because it is well-known and easy to use, and again lightweight. Solo brainstorming is a variation of brainstorming, in which only one person uses the technique [1]. Each participant tries to elicit missing information about the system and its environment. The task was to analyze UML models (structural and behavioral models) to answer the questions “What additional features can be added?” and “What environmental entities are needed for the new features?”. During the analysis the participants were told to keep the following principles (in italics) in mind.

**Go for quantity** This means, one should focus on divergent production under the assumption that a maximum quantity breeds quality.

**Withhold criticism** In brainstorming, criticism of generated ideas should be put “on hold”. Instead, a participant should focus on extending or adding to their own ideas.

**Welcome wild ideas** To get a good, long list of suggestions, wild ideas are encouraged. Going against widely accepted assumptions is actually encouraged.

**Combine and improve ideas** When searching for new ideas one can combine and improve ideas in any way imaginable as this may create more and better ideas.

The result of the application of solo brainstorming is again a list of textual requirement fragments.

### 4 EXPERIMENT DESIGN

The goal of this experiment is to understand the effect of creativity techniques during the elicitation of adaptive requirements.

**Variables.** For answering the research questions we identified three independent variables: creativity technique, case study, and order.

\(^1\)Part of the experiment package https://doi.org/10.5281/zenodo.5801299
We use the two creativity techniques *AdaptationExplore trigger questions (TQ)* and *solo brainstorming (BS)*. As case studies we use two systems, a cyber-physical system (CPS) that implements a *Public Street Light (PSL)* and an app called *Feed me, Feed me (FF)* to ensure that the results are not particular to a certain domain or system type.

The third variable is used to investigate the carry-over effect, see Borden and Abbott [4]. As the authors suggested, we used the order in which the participants perform both techniques as an independent variable to ensure that there is no undetected influence of a carry-over effect, e.g., a learning effect.

The dependent variables are the *number of requirement fragments* gathered during elicitation and the utility of the techniques from a user perspective.

**Definition of Hypotheses:** Based on the variables we defined the following hypotheses to answer the research questions.

To answer *RQ1* we formulate the following hypotheses:

- \( H_{1,1} \): “AdaptationExplore Trigger questions (TQ) produce more requirement fragments than solo brainstorming (BS).”
- \( H_{1,0} \): “AdaptationExplore Trigger questions (TQ) do not produce more requirement fragments than solo brainstorming (BS).”

For *RQ2* we formulate the following hypotheses:

- \( H_{2,1} \): “AdaptationExplore Trigger questions (TQ) have a higher subjective usefulness than brainstorming (BS).”
- \( H_{2,0} \): “AdaptationExplore Trigger questions (TQ) do not have a higher subjective usefulness than brainstorming (BS).”

We employed a 2x2x2 fractional factorial design. The three factors are: the technique (TQ, BS), the case study (FF, PSL), and the order of the techniques (BS-TQ, TQ-BS). A fractional design was used to build groups with a sufficient number of participants. We excluded groups that would force participants to repeat a technique or a case study to eliminate the risk of a learning effect. The participants were randomly assigned to the four remaining groups. Each group performed both techniques on both case studies. The groups applied the techniques in different order. This design allows us to study the effect of the technique, the case study, and the order in which the techniques were applied. The design is shown in Table 2.

**Definition of Metrics.** To measure the two dependent variables we define the following metrics.

- \( M1 \) number of fragments
  - \( \# \) requirement fragments (\#RF)
  - \( \# \) adaptive requirement fragments (\#ARF)
- \( M2 \) subjective usefulness

*Number of requirements fragments (M1 (a)): We accept functional requirements, quality requirements and constraints (according to the IREB definitions). The requirements template from Rupp et al./IREB [23, 25] serves as reference for functional requirements. Beside the legal obligation (like “The system shall”), the requirements template consists of a process verb which characterizes the system activity, an object (plus additional details), and a logical or temporal condition. Each textual statement resulting from trigger questions / brainstorming that covers parts of this classification is counted as a requirement fragment. Table 3 provides examples of real fragments (highlighted) for the public street light. For illustrative purposes, we enriched these fragments with some domain knowledge (in braces). Example 1 is a minimal requirements fragment which includes an activity and an object. Example 2 shows a condition, Example 3 a constraint.

*Number of adaptive requirements fragments (M1(b)): We use the definition of an adaptive requirement from Qureshi and Perini introduced in Section 3.1 as a reference for counting. Example 4 shows a condition or event that triggers an adaptation (monitoring specification). Example 5 describes a base functionality with an alternative realization. Example 6 includes a variability in the operational context that would require an adaptation. If a textual statement covers parts of the reference definition, we count it as adaptive requirements fragment.

All content related to requirements produced by the participants were separated from the general survey answers during the measurement and classification of either requirements fragments or adaptive requirements fragments. This should ensure information on the used technique should not influence requirements classification.

*Subjective Usefulness (M2) of the technique is a subjective impression of the usefulness as perceived by the participant and is measured as a value between 1 ("not useful") and 5 ("very useful").

**Participants.** The empirical study was performed during the “Requirements Engineering” lecture at the University of Applied Sciences and Arts Dortmund, Germany in the winter term 2019/2020. 85 Master students from computer science, medical informatics, business information systems, and an international study program called “Embedded Systems for Mechatronics” participated in the empirical study.

**Experiment Setting and Materials.** Each participant used his or her own notebook with an online form and a paper handout with the case study description during the experiment. We used two academic case studies from literature. Both are formulated openly in order to promote creativity during the identification of requirements. Although the case studies should be known by the participants and contain a need for adaptation. *Public Street Light* describes a smart street light, and is described in [15]. The main functions are *light the street* using motion sensors to detect vehicles and humans and dynamically adjust the street light to save energy and reduce light pollution. Other functions include a *parking space assistant* that sends information about the free parking spaces and highlights free parking spaces (blue color) and *ambulance warning* that is change the light color to red, for other cars to secure the path of an ambulance.

*Feed me, Feed me* is described in [2]. It is an IoT-based ecosystem to support food security, ensure sufficient, safe, and nutrition food to the global population. At the personal level (focus in our case study), the app monitors the user and its environment to provide suggestions on individual activities, health, and nutrition.

A double-sided handout for the participants contained an introduction to the case, a textual description of a situation, and a structural and behavioral model of the situation represented as a UML class and a sequence diagram, respectively. The handout frees participants from juggling between different windows on the notebook screen.

*Online Form:* We used an online form for data collection. The form contained three parts. The first part contained general questions like age and previous experiences. The second and third part contained the questions related to the techniques (the order of the techniques is depending on the group). A short textual description was given at
Table 2: One-half fractional factorial design: AdaptationExplore Trigger Question (TQ), solo Brainstorming (BS), Public Street Light (PSL), Feed me, Feed me (FF)

| Group | 1st Technique | 2nd Technique | 1st Case Study | 2nd Case Study | Number of Participants |
|-------|---------------|---------------|----------------|----------------|------------------------|
| 1     | BS            | TQ            | BS             | FF             | 22                     |
| 2     | TQ            | BS            | FF             | PSL            | 21                     |
| 3     | BS            | TQ            | PSL            | FF             | 21                     |
| 4     | BS            | TQ            | FF             | PSL            | 21                     |

Table 3: Examples of Requirements Fragments

| Requirement Fragments | Adaptive Requirement Fragments |
|-----------------------|--------------------------------|
| (1) [Solar panels shall be attached to the street light...] Using Solar Energy | (4) [The lighting of the street shall depend on...] weather changes |
| (2) [The street light shall react on ...] Car enters highlighted parking spot. | (5) [The street light shall highlight the way to a free parking space...] depending on light bulb working; alternative: displaying in app [..display the parking space in the connected app] |
| (3) [The street lights shall be connected via wi-fi...] connections via wi-fi and bluetooth can not reach lights that are too far away (connection) | (6) When an ambulance is coming and at the same time someone is looking for a parking place then the street light must decide which light will be used and so the other function can obstruct. |

the beginning of both technique parts. For BS the form contains a text field to enter all produced fragments and a question about the usefulness of the technique. For TQ the form contains a text-field for every question to enter the produced fragments and a question about the usefulness of every individual question and the overall technique. The three parts were separated on individual pages so the participants could focus on a specific task.

A package with the full experimental materials, scripts, and results is available online.2

Procedure. The empirical study has started with a 20 min training session that included a motivation of the experiment, an introduction into adaptive systems and elicitation of requirements, a presentation of the experiment materials, and an explanation of techniques.

After the training the participants were randomly assigned to four groups. The printed documents were distributed and all students tested the access to the online form. The students filled out a pre-questionnaire about their background (e.g., skills, motivation).

The experiment was carried out in two iterations of 45 minutes each. After 40 minutes a notification was given to finish the writing before the experiment had started (2 cases); (2) if a participant did not adhere to the experiment procedure in one of the following ways: (1) if a participant had taken too much time (above 2h) or started the experiment had started (2 cases); (2) if a participant did not finish the application of a technique, that is they reported no fragments at all (6 cases); (3) if a participant did not follow the description of the techniques (e.g. trying to perform one technique on both case studies) (4 cases). 73 records remained for further analysis.

5.1 Effectiveness

The discussion of results is structured along our research questions.

RQ1: “Is our approach relying on trigger questions more effective regarding the number of collected requirement fragments?” We first present the descriptive statistics.

The following figures compare #RF and #ARF for all three factors. Figure 1 shows the #RF in relation to technique, case study, and order. Figures 2 and 3, show the #ARF and the sum of #RF and #ARF, respectively. The figures show that AdaptationExplore trigger questions produce more fragments in all cases. Moreover, AdaptationExplore trigger questions produce slightly more fragments for FF if the participants had to start with brainstorming in the first iteration.

Figure 4 illustrates how many fragments were identified using a particular question. The #RF and #ARF are provided for each question. The overall number of fragments varies a lot. The total number of ARFs (284) is lower than the total number of RFs (664). In most cases, the bias of a question is towards RFs, in the case of Q6, Q11, Q12, Q13 it is towards ARFs.

For the one-tailed hypothesis $H_1$ we use an ANOVA to test whether the number of fragments depends on one of the three independent variables. We use a Type III ANOVA as the group sizes are not equal. ANOVA assumes normal distribution and homogeneity of variance. We used the Levene test to check the homogeneity of variances [14]. Based on the result $p = 0.16535 > 0.05$, we can accept homogeneity. However, normal distribution for #RF is not given according to a Shapiro-Wilk test. The Q-Q plot [14] provided in Figure 5 shows that

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2https://doi.org/10.5281/zenodo.5801299
#RF is close to normal distribution (shaded area). As the ANOVA is reported as relatively robust against violation of normality, we proceed and provide the results of the ANOVA in Table 4.

As the Levene test failed to show homogeneity for #ARF, we applied a robust ANOVA [14, 18]. The results are provided in Table 4. The ANOVA shows that the technique had a significant influence on #RF and #ARF. With respect to #ARF, we can also identify a weaker significance for the case study\((p = 0.0910)\), for the combination of case study and order\((p = 0.0120)\), and all three variables technique, case study, and order\((p = 0.0170)\). In the sum of #RF and #ARF shown in the third part of the table, a significance for case study\((p = 0.0870)\) and the combination of technique, case study, and order was identified\((p = 0.0790)\).

As we found significant variations, we continue with a pairwise t-test to compare the means of the treatments and to accept or refute the hypothesis. We choose a more strict significance level of 0.01 (instead of the usual 0.05) as the test of several hypotheses could otherwise lead to incorrect significant values. We performed a t-test for \(H_{1,1}\) for the technique, as the ANOVA indicated a significant difference in the variances. A pairwise t-test resulted in the following p-values: \(p \leq 0.0001\) for #RF, \(p \leq 0.0001\) for #ARF, and \(p \leq 0.0001\) for the sum of #RF and #ARF. Thus, we have identified a significant impact of the technique on the number of fragments in all cases. That is, we can reject the null hypothesis and accept hypothesis \(H_{1,1}\).

**Discussion.** The application of AdaptationExplore trigger questions produces significantly more adaptive requirements fragments than solo brainstorming \((H_{1})\). We could also show that AdaptationExplore trigger questions produce more requirements fragments. We could not show a carry-over effect as the order in which trigger questions and brainstorming were applied does not have a significant impact. However, the case study had a weak significant impact. For the street light case study, the participants reported a lower #RF than for Feed me, Feed me. One reason could be the domain of the case study. The Feed me, Feed me case study is about a fitness gym, which might be more familiar to the participants than a public street light. Another explanation could be that Feed me, Feed me leaves more room for creativity. Additional analysis on the influences of the groups, native language, and time did not expose any significant influences on the #RF and #ARF.

**5.2 Usefulness**

**RQ2:** “Is our approach perceived as more useful than brainstorming from a user perspective?” The overall usefulness of the two
Table 4: ANOVA Results - Significance codes: '****' 0.001 '***' 0.01 '**' 0.05 '*' 0.1

| Variables                       | Sum Sq | DF | F value | P value |
|---------------------------------|--------|----|---------|---------|
| Technique                       | 154.22862 | 1  | 8.85567 | ** 0.00345 |
| Case study                      | 2.04844 | 1  | 0.11762 | 0.73215 |
| Order                           | 0.39709 | 1  | 0.02280 | 0.88020 |
| Technique:Case study            | 16.28592 | 1  | 0.93512 | 0.33523 |
| Technique:Order                 | 11.63938 | 1  | 0.66832 | 0.41505 |
| Case study:Order                | 4.45675 | 1  | 0.25590 | 0.61376 |
| Technique:Case study:Order      | 6.66140 | 1  | 0.38249 | 0.53729 |
| Residuals                       | 2403.38077 | 138 |         |        |

Robust ANOVA for #ARF

| Variables                       | value | P value |
|---------------------------------|-------|---------|
| Technique                       | 77.07816 | *** 0.0001 |
| Case Study                      | 3.04256 | 0.0910 |
| Order                           | 0.22366 | 0.6400 |
| Technique:Case Study            | 2.31356 | 0.1380 |
| Technique:Order                 | 0.01363 | 0.9080 |
| Case Study:Order                | 7.03659 | * 0.0120 |
| Technique:Case Study:Order      | 6.34043 | * 0.0170 |

Robust ANOVA for Sum of #RF and #ARF

| Variables                       | value | P value |
|---------------------------------|-------|---------|
| Technique                       | 85.10456 | *** 0.0001 |
| Case Study                      | 3.03689 | 0.0870 |
| Order                           | 0.09954 | 0.7540 |
| Technique:Case Study            | 0.67636 | 0.4150 |
| Technique:Order                 | 2.23148 | 0.1410 |
| Case Study:Order                | 1.71474 | 0.1960 |
| Technique:Case Study:Order      | 3.20470 | 0.0790 |

Figure 5: Quantile-quantile plot for #RF

Figure 6: Usefulness of Questions and Overall Usefulness of Techniques

techniques are shown in the last two columns of Figure 6. The AdaptationExplore trigger questions (3 out of 5) were rated as not as useful as brainstorming (4 out 5).

Regarding the hypothesis H2 we performed a one-tailed Mann-Whitney U test. We tested for the usefulness of the AdaptationExplore trigger question being greater than brainstorming. The result was \( p = 0.9998 \). This means that we could not accept H2.1. For the discussion of the results we performed a second test to analyze the effect of brainstorming on the subjective usefulness. For the second test we used a one-tailed Mann-Whitney U on the hypothesis BS > TQ in terms of subjective usefulness, with the result \( p = 0.0002 \). Thus, the participants even judged the usefulness of our approach as significantly lower than brainstorming.

Discussion. We could not accept our hypothesis (H2.1). AdaptationExplore trigger question were regarded as less useful than solo brainstorming. It is an interesting observation that the participants even produce more fragments using the AdaptationExplore trigger
questions (objective), but rate them as less useful (subjective). One reason could be that the participants deem the prescriptive character of trigger questions too restrictive. Also, a single trigger question produces not as many results compared to the principle of brainstorming, which could lead to the overall impression of being less useful.

**RQ3:** “How effective are the individual trigger questions of AdaptationExplore objectively in terms of collected requirement fragments?” #RF and #ARF are depicted in Figure 4. The results show that the first three questions produced the most requirements fragments.

**Discussion.** RQ3: The questions were designed from being more abstract (Q1) to being quite detailed (Q15). Thus, the abstract questions seem to be more effective than the concrete ones. With respect to #ARF, the effectiveness of the questions vary over the whole question set indicating that fatigue was not a problem. Q6, Q11, Q12, Q14 were specifically designed to spot ARFs and they actually show the best performance.

**RQ4:** “What is the individual usefulness of the AdaptationExplore trigger questions from a user perspective?” The usefulness of each trigger question is illustrated in Figure 6. For the questions Q1 to Q14 the average usefulness was 3 out of 5. Q15 had only a usefulness of 2 out of 5.

**Discussion.** RQ4: The overall usefulness of the questions was rated medium (3) and is in line with the overall rating of AdaptationExplore trigger questions. There are no significant differences between the questions regarding the subjective usefulness as perceived by the participants (see Figure 6). The usefulness of the last question dropped slightly when compared to the previous ones.

## 6 THREATS TO VALIDITY

This section discusses major threats to validity [31].

**Conclusion validity** concerns (statistical) relationship between treatment (techniques) and outcome. We followed the assumptions of the statistical tests when analyzing the results. While we had a rather high number of participants for a Masters course, the design divided this by four leading to group sizes ranging from 16 to 20. A lack of process adherence of participants led to slightly unbalanced group sizes.

We counted requirements fragments produced by the participants in the experiment. While is common practice also in other experiments on elicitation and creativity, it is a sub-optimal measure as there is some ambiguity in how to count: a participant’s statement might contain one or more fragments (also called *idea* in related work). Also the knowledge about the underlying technique could impact the counting process. Thus, we separated the requirements fragments from the gathered survey data to disguise the technique used to produce the fragments. Further, we employed strict counting rules and discussed ambiguous cases among the authors.

**Internal validity** can be affected by a number of factors (a) to (e).
(a) The selection of subjects could be a threat. In this experiment, the students joined on a voluntary basis and were randomly assigned to groups, which should minimize selection issues. (b) All experimental materials are written in English. The participants had a wide variety of backgrounds. 3 native English speakers participated, most of the others (36) reported German as first language, followed by Kanda (10) and Tamil (5). We tested the effect of technique and language using ANOVA, there was no significance with respect to the language.
(c) Each participant had to perform both techniques TQ and BS, which could lead to a carry-over effect. We added order as independent variable to investigate this effect, as suggested by Bordens and Abbot [4]. The result of our tests showed that there is no significant effect for order, see Table 4. (d) Another threat is the quality of the experiment materials. For each case study, the students received a textual description, a class diagram, and a sequence diagram. The material was introduced to the participants before the experiment to make sure the experiment material was understood by all participants.
(e) An unforeseen event happened during the experiment session which caused a slight ceiling effect: some students (22), who came by car left the session 20-30 min before the end. This was probably caused by fear of a traffic jam as extraordinary road restrictions were announced just before the experiment started. Because of the random assignment of participants to groups, we believe this did not influence the main results very much. However, it explains to some extent the relatively low numbers of fragments found in general.

**Construct validity** concerns the relationship between theory and observation. For measuring the usefulness of a question, it is difficult to capture this with a direct question as this gives only the impression of the subject, but not necessarily the true impact. This problem is compounded as the scale used was not a Likert scale. One should also note that the usefulness in a group effort, which is more typical for creative requirements elicitation, may differ from observations in an individualized setup. However, we follow here the lead of some other experiments which made this simplification for higher levels of control of the experiment.

**External validity** concerns the generalisability of results. As with any study using students as subjects, the validity of the population is a concern. The students in our study are on the Master level, with an average age of 26 years, and most of them with some industrial experience. Some of the students even have experience in requirements engineering (up to 5 years). That is, we can consider them as young professionals. Moreover, the studies of Falessi et al. [10] and Salmen et al. [26] investigated the differences in using students and professionals. In both studies no significant differences were observed, especially when testing a new approach, as is the case in our experiment.

## 7 CONCLUSION

The systematic elicitation of requirements for adaptive systems is an important part of software engineering for adaptive systems. In this paper, we evaluated the effectiveness of a technique for elicitation of such requirements, which relies on the use of trigger questions, an approach taken from the area of creativity techniques. We crafted 15 trigger questions and evaluated them in this paper. Our evaluation relies on a controlled experiment that compares adaptation-tailored trigger questions to solo brainstorming as a baseline.

The results are very positive for trigger questions as the number of requirements artifacts produced (both adaptive and other) is significantly higher than with the baseline. Beyond an analysis relying on objective metrics, we also evaluated the subjectively perceived usefulness, which gave rise to a very interesting divergence in the results as participants rated brainstorming as more useful, i.e., exactly opposite of the objective data. We argue that this divergence is a benefit of our
study as such divergences can only be detected, if both subjective and objective metrics are combined, which is only rarely the case. We also evaluated the various trigger questions individually, seeing significant differences in their productivity.

The participants of our experiment were mostly students, but many of them spent a considerable time in industry between their BSc degree and enrollment into the MSc program. We expect that this reduces any concerns regarding the relevance of the results to industrial settings.

Overall, we believe this experiment shows that the use of creativity techniques is a very important for creating better techniques for requirements elicitation for adaptive systems. Moreover, the results of our experiment are in line with the fundamental idea that defining specialized creativity techniques is more effective than general ones.

We see significant potential for future research:

- The current list of triggers was an initial attempt, there are probably possibilities to further optimize them.
- A better understanding of the influence of domain characteristics would be useful. For example, we observed more results for the FF study, but currently it is unclear, whether this is due to domain characteristics, interactions between questions and the domain or a statistical artifact.
- Tool support could be investigated to interactively ask for a specific element, system type, or domain, based on triggers similar to the proposal by El-Sharkawy and Schmid [9].
- The divergence between objective and subjective measurement leads to questions: where does this divergence come from? This leads to a general question: how an objectively well-functioning approach can be improved to be subjectively more interesting and more useful for users (with the restriction to remain objectively superior).

We regard especially the last point as very important as it provides a direct path to method adoption as we assume that independently of the objective data, only methods will be adopted by engineers that also feel right to them, i.e., that are also subjectively productive. We also believe that while this divergence may look like an issue in our results, it is actually a virtue as such divergences are rarely discussed, even though, we believe they are rather common.

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