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Creativity Triggers: Extension and empirical evaluation of their effectiveness during requirements elicitation ☆

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ABSTRACT

Creativity helps organization to produce novel solutions to complex and sometimes enduring problems. By breaking traditional ways of looking at a given problem and facilitating the design of alternative approaches, creativity contributes to the creation of value-adding solutions within an organization. This is true for any type of problem, including the problem of specifying the requirements for a new software or system. A number of creativity methods, techniques and tools have been proposed as a way to be more creative during Requirements Engineering (RE). They are however often demanding in terms of time, human involvement and resources, thereby reducing their attractiveness for RE practitioners and their stakeholders. Our previous research has led to the proposition of a lightweight tool to support creativity in RE; the Creativity Triggers (CTs). CTs are cards to be used during requirements elicitation to foster creativity from stakeholders and help them uncover novel features of a system-to-be. This paper builds on – and extends – our early conceptualization of CTs to produce a more comprehensive and empirically grounded proposal. Our contribution is twofold; first, we conduct a large-scale and systematic exploration of the qualities underlying the CTs. The objective is to improve the completeness of the tool in order to produce a final set of CTs. Second, we conduct a validation of CTs in different contexts and with different viewpoints to evaluate its usefulness in supporting creativity during requirements elicitation. We end-up with a set of 22 CTs that provided evidence for supporting creativity during RE.

1. Introduction

In an increasingly competitive society, companies nowadays shift towards creative thinking to pursue their business (Ilmafa'ati et al., 2021; Santos et al., 2022). Creativity helps them to bring innovation to their way of working and to produce novel solutions to complex and sometimes enduring problems. By bringing creativity into the equation, the design of products or services – or simply *solutions* in the remainder of this paper – becomes more exploratory. Instead of looking for the right answer to a given problem, the focus is now on bringing new solutions to unknown problems uncovering new business opportunities. Exploration is crucial to discover the unconscious customers' needs before they emerge on the market and hence obtain substantial competitive advantages (Maiden et al., 2010). By breaking traditional ways of looking at a given problem and facilitating the design of alternative approaches, creativity contributes to the creation of value-adding solutions (Nguyen and Shanks, 2009). The qualities behind the creative essence of ideas repeat across any type of project. Previous observations reveal to be very relevant for the problem of specifying requirements for a new software or system (Saha et al., 2012), a process usually referred to as *Requirements Engineering* (RE). RE is the iterative process that discovers the requirements of a system-to-be by identifying the involved stakeholders along with their needs (Nuseibeh and Easterbrook, 2000; Pohl, 1996; Yu, 2002). With the increasing recognition of the importance of creative thinking, RE practices need to adapt to focus more on innovation and innovative outcomes. One way to do this is to support analysts to explore their problems and potential solutions more effectively. As a consequence, new RE practices have emerged, for instance to use during Agile development projects (Heikkilä et al., 2017; Aldave et al., 2019)

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or alongside equivalent Design Thinking processes (Hehn and Uebernickel, 2018; Hehn et al., 2020; Pereira et al., 2021).

An abundance of techniques exist to support creativity in general, regardless of the application domain and specifics of the solutions. We review them in Section 2.1. Some techniques have been adapted to optimize creativity in the particular context of a RE process, but present two main limitations. First, existing techniques are quite demanding in terms of time, human involvement and/or other resources, somehow inhibiting their attractiveness for RE practitioners and their stakeholders (Lemos et al., 2012). Second, some of the existing tools lack systematic empirical evaluation. Put together, these limitations constitute a barrier to the systematic adoption of creativity support during RE (Lemos et al., 2012). To deal with this gap, our previous research has led to the proposition of a lightweight tool in Burnay et al. (2016) to support creativity in RE; the Creativity Triggers (CT). The tool is intended to be lightweight, i.e. easy-to-use, meaning that its use is straightforward and inexpensive (in time, money or resource). The tool takes the form of cards to be used during elicitation of requirements; more precisely during requirements elicitation which stands to be the very first step of requirements elicitation during which wants and needs are explored (Robertson and Robertson, 2012). This use aims to foster creativity from stakeholders and to help them uncover novel features of a system-to-be. Each card represents one trigger – a quality linked to innovation – and presents some avenues of thinking. Exposing the cards to stakeholders must be sufficient to trigger their creativity.

The current paper builds on – and extends – our previous work on CTs. Our contribution is twofold; first, we conduct a large-scale and systematic exploration of the qualities underlying the CTs while the first paper proceeded only with limited data collection. The objective is to improve the completeness of the tool in order to produce a final set of CTs increasing the number and the representativeness of the triggers. Second, we conduct a validation of CTs in different contexts and with different participants to evaluate its usefulness in supporting creativity during requirements elicitation while the first paper focused on the validation of CTs structure and applicability to elicitation. We end up with a set of 22 CTs that proved to support creativity during RE. The underlying motivation is that very practitioner should be able to incorporate creativity in the RE process (Nguyen and Shanks, 2009; Maiden and Robertson, 2005; Nguyen et al., 2000; Nguyen and Swatman, 2003), as reflected clearly in contributions like (Hoffmann et al., 2005; Nguyen and Shanks, 2006; Mahaux et al., 2013) that propose a deep understanding of Creativity within a RE context. This, in turn, creates a need to develop new supports that foster creative thinking in RE. In this paper, we explain and discuss the use of CTs within the RE Roadmap (Nuseibeh and Easterbrook, 2000) which frames the background of any RE process.

The remainder of this paper is structured as follows. In Section 2, we first review the literature about the creativity and its various support. We present the theoretical background of creativity necessary for the understanding of this work in Section 2.1. We then outline how Creativity Triggers contribute to the field of Software Engineering in general and we make a state of the art of creative support in Section 2.2. Section 3 elaborates on methodological questions related to the use of Creativity Triggers. We clarify how they can be used as part of a broader RE methodology and we depict an usage protocol. Section 4 then describes a full exploratory study we conducted to design a ready-to-use version of CTs by increasing their completeness, while Section 5 reports on a systematic evaluation of the CTs. Finally, we conclude this work by summarizing our findings and presenting future researches in Section 6.

2. Literature review

CTs were proposed by James and Suzanne Robertson, who introduced them informally based on their experience as requirements engineers. The triggers have then been used by the Robertsons during field sessions with stakeholders and through workshops like in Schlosser et al. (2008). However, their were neither scientific foundation nor systematical formalization. At that time, the CTs were presented as an idea for which further research seemed necessary since they yielded promising insights regarding the creative support it gave. To explore the actual value of CTs, we led an exploratory study about the CTs in Burnay et al. (2016). This study aimed to formally present them to the research community, to validate a first and early design and to reflect on how they may work. In this early study, the tool was not complete yet and a more systematic validation was needed. The present work comes as an extension to this.

2.1. Creativity background

This paper considers creativity as a mental process which aims to produce ideas or concepts that share two characteristics: the *usefulness* and the *novelty* (Anon, 1998). This definition is aligned with many existing contributions on the topic (Maiden et al., 2010; Nguyen and Shanks, 2009; Bourgeois-Bougrine et al., 2017). We use the term *ideas* in the remainder of this paper to refer to the outcome of a creative process. Ideas need to be useful in the sense of being appropriate to the task. In Charyton et al. (2011), Charyton et al. define the usefulness as the ability of the ideas to meet the required functionalities and the convenience of the ideas to be translated into practice. Relative to RE, a requirement will be useful when it is feasible and solves a problem matching the environment constraints, i.e. solving the requirements problem (Jureta et al., 2014). Ideas also need to be novel. They must bring something new, arousing a kind of unexpectedness. This is often referred to as the "originality" of the solution.

Creative thinking can be articulated into two processes; *divergent thinking*, and *convergent thinking* (Carroll and Guilford, 1968). The *divergent thinking* is the process that generates several solutions for a given problem. The focus shifts towards the quantity of solutions that must be found in a short period of time. This process is characterized by its unsupervised and unorganized context ensuring a lot of ideas emerge randomly. It starts from an initial concern and "goes outside" (i.e. the word "divergent") by exploring the field of possibilities to find many ideas, as depicted in Fig. 1(a). In contrast, the *convergent thinking* is a structured process intended to find "the" appropriate solution to a standard and formal question. It starts from several observations, facts, ideas and "converges" to the appropriate solution(s), as depicted in Fig. 1(b).

While divergent thinking and convergent thinking can be seen as opposing processes, they are usually coupled together. When divergent thinking would better fit a changing environment, convergent thinking on its side would formally tackle an issue in a linear manner. In practice, divergent thinking will explore a broader range of ideas and will produce an unstructured output. This latter then needs to be organized through convergent thinking.

Hereinafter, we will see how CTs are linked with both processes (refer to Section 3).

Broadly speaking, creative outcomes can be categorized into three types; (i) *historical creativity* (Boden, 2003) which generates ideas new to the human-kind, (ii) *psychological creativity* (Boden, 2003) which proposes ideas that are novel for the person who comes up with the ideas, (iii) *situated creativity* (Suwa et al., 2000) which brings ideas new to a particular social group or specific

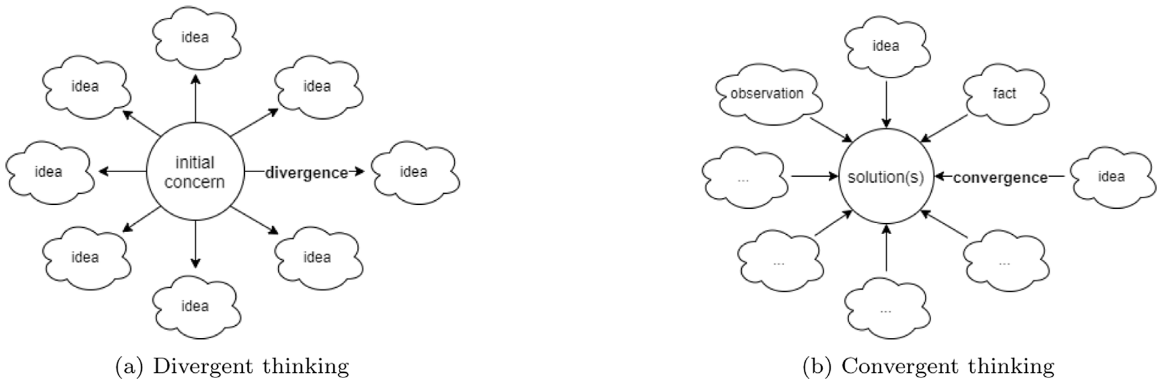

Fig. 1. Thinking processes.

situation. In general, we consider the creativity in RE as a situated creativity whose ideas do not necessarily need to be novel for the entire human history (Suwa et al., 2000), and so is the focus of CTs.

2.2. Creativity support state of art

Supporting creative thinking is not a new idea, and a multitude of approaches that help to be creative exist. Some are domain-independent, and come with no specific assumption or requirements about the context of use or field of application. This is the case for instance of support like: the *Six hats of thinking* (De Bono, 2017), the *Brainstorming* (Osborn, 1953) and *Reverse Brainstorming* (Souder and Ziegler, 2016), the *Problem Reversal* (Thompson, 1992), the *Mind-Mapping* (Buzan, 1983), the *Lateral Thinking* (De Bono, 1995), the *Gordon Method* (Gordon, 1961), the *Creative Problem Solving* (Parnes, 1992), the *TRIZ* approach (Savransky, 2000), the use of *Persona* (Pruitt and Grudin, 2003), the *5 Whys* technique (Serrat, 2017), etc. Other general support for creativity can be found in Souder and Ziegler (2016). While these are useful with regards to creativity, they remain generic and miss a number of specifics of the RE context. For instance, they are not designed to fit the RE workflow, they are not focused on product/services features, and so on.

While a multitude of general creative techniques exists, we notice that there is only a limited number of RE creative tools. In the subsequent paragraphs, we give an overview of some creative approaches that can be used during RE. We only selected the most developed/robust and the most recent approaches. For a systematic literature review of creativity support in RE, the reader can refer to Lemos et al. (2012), Aldave et al. (2019) and Saha et al. (2012).

EPMcreate (Mich et al., 2004) relies on the Elementary Pragmatic Model (De Giacomo, 2012) used by psychotherapists to model the human mind and to organize the pragmatics of communication (Mich et al., 2004). It helps RE practitioners identify the position of several stakeholders on multiple topics and to envision several behaviors that one stakeholder can have towards the other stakeholder's point of view. The combination of the initial stakeholder's viewpoint and the reaction of the other stakeholders creates a new position from which creative ideas can be generated. In this technique, a considerable number of steps need to be implemented. Indeed, for each pair of stakeholders, the practitioner considers among 16 possible behaviors – represented by 16 Boolean functions – that the stakeholder can have. The number of stakeholders to be considered is left to the practitioner's choice. The number of iteration will thus increase with the number of possible stakeholders' pairs that are considered.

Others approaches (Bhowmik et al., 2015; Do et al., 2020) try to automate the generation of requirements for software by reusing existing ones. For instance, the technique of Bhowmik et al. (2015) is based on the combinatorial creativity (Boden, 2003) principle that unfamiliar connections will be created among familiar ideas. First of all, the framework identifies stakeholders with their requirements on a piece of software. Stakeholders that share common interests are grouped together. The ideas within a particular group are considered as the *familiar ideas*. Unfamiliar connections are then made among these familiar ideas and generate new creative requirements. To create these connections, the framework follows syntactic tools (for instance, by playing with the *Part of Speech* of words). This approach requires that the system and the documentation of its stakeholders' network already exist.

A third example is a methodological layer that is added to the traditional flow of RE to incorporate the use of general creative tools (Vieira et al., 2012; Horkoff and Maiden, 2016; Nguyen and Swatman, 2006; Grube and Schmid, 2008; Pereira et al., 2021). For instance, the *Creativity Patterns Guide* (Vieira et al., 2012) advises the user on which creativity technique fits the best the particular RE step. Another case is *Creative Leaf* (Horkoff and Maiden, 2016), a tool that directly integrates general creativity tools in a requirements modeling language, namely i^* (Yu, 1997). Other examples have sought to extend RE processes with established Design Thinking techniques, in order to make these RE processes more flexible, human-centered and innovative (Pereira et al., 2021).

Yet another method to integrate creativity in a RE process is the use of multi-day workshops (Maiden and Robertson, 2005; Jones et al., 2008; Maiden et al., 2004a; Hollis and Maiden, 2012). They are often structured into several sessions during which creativity techniques are applied with the participants. One example is called APOSDLE (Jones et al., 2008). This was a two-day workshop that was articulated in 4 sessions. During these, creativity techniques (like *Round-Robin*, *constraints removal*, etc.) were applied to incorporate the three type of creativity depicted by Boden; the exploratory, the combinatorial and the transformational (Boden, 2003). Another example of such workshops is called *Requirements Engineering with Scenarios for User-Centered Engineering* (RESCUE) (Maiden and Robertson, 2005). RESCUE was a scenario-driven approach in which several sessions were followed to also incorporate the three type of creativity (Maiden and Robertson, 2005) in a RE process. Creativity techniques, modeling and analysis took place to arise creative thinking, contributing to use case specification and uncovering systems requirements. An example of RESCUE application can be found in Maiden et al. (2004b), where the approach had been applied to manage flight departures in an airport case study. Such workshops proved to be useful for its users. As a direct consequence of this completeness, they are time, effort and resources demanding restricting their scalability.

In the *AnTiQue Module* (Zachos and Maiden, 2008), authors propose to foster creativity as a way to complement the requirements of a web service. The tool retrieves web services that are technically analogical to the one of interest but that come from different application domains. For instance, a *find-and-book cinema ticket service* and a *find-and-book parking place service* are technically analogical, i.e. they share similar functionalities, but come from different application domains, respectively a cinema and a parking domain Zachos and Maiden (2008). Among these analogical matches, the tool finds dissimilarities that will ultimately specify novel requirements for the web service.

Other work had been focused on arising creativity in distributed work environments (Ghanbari et al., 2015; Aaen, 2008). This is the case of *Innovation requirements elicitation* (Ghanbari et al., 2015). The authors propose a comprehensive approach which uses serious games in requirements elicitation. It offers two advantages; first, serious games themselves contribute to the creativity of the user. Second, online tools for serious game offer a suitable platform for distributed collaboration. The approach is empirically evaluated in Ghanbari et al. (2015).

The last example is called *Design to Connect* (D2C) (Bleuzé et al., 2014). The tool consists of a deck of 46 cards which helps designers to generate new connections in products, with a *connection* being defined as *"an interface between parts or functions and can be virtual or physical"* (Bleuzé et al., 2014). Each card presents a *Heuristic* which removes, creates or enhances a connection. The D2C can also be employed during elicitation phases to generate some kind of new requirements. However, the types of the generated requirements are different. The D2C tool stands for creating new connections within the parts of the solutions during its design. To focus on that particular aspect, i.e. the connections, the D2C tool is built from the *Connections Design Considerations* framework. Each card is thus based on heuristics and on expert designers which makes it more specific to a function or a characteristic of a solution.

All in all, the above approaches present some drawbacks. Some of these approaches remain general, providing only conceptual guidelines on how to incorporate creativity. Most of the other techniques require a heavy implementation, making them highly demanding on time, resource or money (Lemos et al., 2012). Some are restricted in their application scope. Others require that the solutions for which creative requirements need to be discovered already exist making the approach dependent on some documentation (for instance, the stakeholders' network). The CTs try to mitigate these aspects by being a tool, as opposed to conceptual guidelines. The tool is intended to be lightweight, requiring less resources or prerequisite knowledge, i.e. anyone in possession of the tool is able to use it. There is no specific need to have a leader conducting the discussion as the tool is self-explanatory. The CTs are not restricted to a specific type of solution and can be used with existing but also completely new solutions. Therefore, they do not depend on any form of already-done documentation. Table 1 summarizes the creative support mentioned earlier.

3. Integrating CTs in RE methodologies

This section demonstrates how the CTs can be integrated in a RE process. CTs were developed to be *lightweight*, *self-explanatory* and not requiring any prior knowledge to use. However, it is important to demonstrate how CTs could be integrated in a RE process. This section describes how CTs fit into one traditional RE process based on the RE Roadmap (Nuseibeh and Easterbrook, 2000) and Design Thinking processes (Brenner et al., 2016). It then defines one protocol to guide users in using the CTs during a RE process.

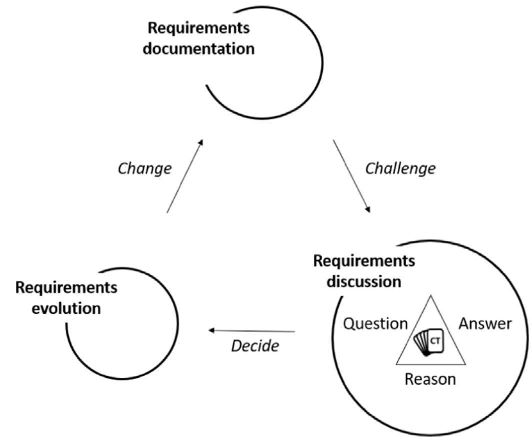

Fig. 2. CT within the *Inquiry Cycle model* based on Potts et al. (1994).

3.1. CTs in RE flow

There is a wide variety of ways that RE processes can be conducted. In this paper, it is not possible to demonstrate how CTs can be integrated into all of them. Instead, we built on the well-established Requirements Engineering Roadmap of Nuseibeh and Easterbrook (2000), which provides a general framework for most RE processes. The roadmap defines 5 RE core activities; (1) requirements elicitation, (2) requirements modeling and analysis, (3) requirement communication, (4) requirements agreement and (5) requirements evolution. Elicitation is recognized as the first activity of most RE processes. Elicitation is the task of discovering requirements by exploring the problem domain with stakeholders, and about identifying stakeholders, system boundaries, constraints, goals, tasks and usage scenario's. There is a matter of uncovering the *unknown*. We assert that it is one activity for which CTs can be used.

Furthermore, Nuseibeh and Easterbrook (2000) propose one concrete method for eliciting requirements; the Inquiry Cycle (Potts et al., 1994). The Inquiry Cycle is composed of three activities (Fig. 2); requirements *discussion*, *evolution* and *documentation*. The discussion activity involves questions that trigger a discussion, answers to these questions that represent solutions, and reasons that are details for each solution's relevance. So furthermore, also assert that CTs can be used to trigger more creative discussions about requirements to elicit and discover.

In addition, RE can be made more flexible and innovation-focused by extending it with Design Thinking practices (Hehn and Uebernickel, 2018), and we also assert that CTs can be integrated into these practices to increase their creative potential. Most Design Thinking practices are composed of five core activities: *Empathizing*, *Ideating*, *Defining*, *Prototyping* and *Evaluating* (Brenner et al., 2016). The authors have applied CTs previously to enhance creative thinking during the Empathizing and Ideating activities when exploring the problem and generating new ideas to solve it. Indeed, the role of creativity in design thinking is often under-played. For example, Lockwood characterizes Design Thinking as a process of observation, collaboration, fast learning, visualization of ideas, rapid prototyping and concurrent business analysis (Lockwood, 2010), rather than one that promotes creative thinking.

Therefore, we assert that CTs have the potential to be integrated effectively in both these and other established RE and Design Thinking processes as well as emerging hybrid processes (Hehn and Uebernickel, 2018), and we hypothesize that their use can increase the volume and quality of creative outcomes.

Table 1
Literature review summary.

Approaches	Core concept	Advantages	Differences with CTs
EPMcreate (Mich et al., 2004)	Combines multiple positions from stakeholders to generate new creative positions.	All combinations of viewpoints of pairs systematically explored.	CTs are a lightweight tool, do not vary with stakeholders number nor in steps.
Combinational framework (Bhowmik et al., 2015)	Creates unfamiliar connections of familiar ideas.	Automated generation.	CTs work with new solutions that are not software, no stakeholders' network dependency.
Approaches like (Vieira et al., 2012; Horkoff and Maiden, 2016; Nguyen and Swatman, 2006; Grube and Schmid, 2008; Pereira et al., 2021)	Organize and structure general creativity support within traditional RE process.	Effectively support creativity, fit RE flow.	CTs require lighter implementation, less prerequisite knowledge.
Creative Workshops (Maiden and Robertson, 2005; Jones et al., 2008; Maiden et al., 2004a; Hollis and Maiden, 2012) (e.g.: RESCUE, APOSDLE, ...)	Workshops that incorporate several creativity techniques.	Supports several types of creativity.	CTs are less demanding in time and resources.
AnTiQue Module (Zachos and Maiden, 2008)	Generates ideas from technically similar web services from different domains.	Physical and automated support.	CTs do not require a specific type of solutions.
Innovation requirements elicitation (Ghanbari et al., 2015)	Use serious games to support creativity in a distributed context.	Overcome the limitations of off-site collaboration	CTs are built on empirical innovation qualities, ca be also used with less than 5 stakeholders
D2C tool (Bleuzé et al., 2014)	Generates new connections for products or services.	Physical support and lightweight tool.	CTs are built on empirical innovation qualities, more generic.

3.2. CTs usage protocol

The RE process chosen by the RE engineer will determine when the CTs need to be used. By contrast, the protocol reported in this section describes how to use CTs in one of these RE processes. Although CTs are self-explanatory and can be used without a protocol, we systematically applied the following protocol during the studies, to reduce sources of bias:

1. Identify the problem to be addressed with the help of CTs;
2. Select between 3 and 5 CTs; selection can be random or adapted to the specifics of the application domain (in which case the engineer selects the CTs)
3. Print each CT and display to participants (pin on a wall, on a board, on table);
4. *Take-off* (exploring ideas) — For each CT card:
   - Let participants read the CT card;
   - Invite participants to react (what is clear/unclear, how the card is understood, does it ring a bell, etc.). This will generate a discussion around the card;
   - Invite participants to link the card with the problem of interest (how can the card help to solve the problem);
   - This will produce new idea that must be written down and linked to the current CT card (using color sticky-notes, virtual board, etc.);
   - Continue as long as new ideas are produced then go to the next CT or to step 5;
5. *Head-to* (structuring ideas) — try to sort things out with participants in order to identify potential solutions. Each CT has produced a group of idea. For each group, elaborate on most valuable/novel ideas, merge similar ones, adapt those that are not directly feasible.
6. *Land-on* (selecting solution) — ask participants to evaluate which of the considered solutions best solves the problem identified in step 1. To select idea, several methods can be used and it is up to the RE engineer to select one (e.g.: voting, idea weighting, etc.). If no solution appears, start again as step 2 with a different set of CTs.

The *Take-off* step encourages divergent thinking using the CT card as the trigger for a discussion that generates numerous ideas. All generated ideas are grouped by the CT card that produced them. A review of the ideas in each group reveals dominant ideas and themes, the innovation directions supported by most ideas, as well as the themes and innovation directions not supported by ideas. By contrast, the *Head-to* step encourages convergent thinking by structuring the unstructured outputs of the *Take-off* step. For each given group of ideas, users evolve the ideas into more concrete solution(s). Both steps are intended to make the CTs understandable, and simple to use.

4. Study 1: Exploratory study

In this first qualitative and exploratory study, we significantly extended the creation process of the CTs as suggested in Burnay et al. (2016). For this study, the objective was to answer the following **RQ1** — *which are the qualities that make an end-user consider a solution as innovative?* To answer this question, we disseminated a survey to collect qualities associated by people to innovation. Then, we made use of data mining techniques to extract clusters from the gathered qualities with the objective of producing a final and complete set of CTs cards.

4.1. Methodology

4.1.1. Data collection

The very first step of study 1 was to collect data using an online survey to understand what qualities people associate with innovative solutions. The assumption underlying this methodology was the same as in Burnay et al. (2016); if we can identify the qualities that people link frequently to novelty and usefulness, we could then reuse those qualities in different contexts to foster the production of creative ideas.

Our *sampling strategy* was purposive. We did not restricted the sample to specific characteristics. Indeed, the objective of the survey was crowdsourcing. The idea was to brainstorm with people — i.e. anyone who have already be the *end-user* of an innovative idea. We wanted to get as much data as possible to feed our data algorithm (see Section 4.1.2). The survey was shared online in several countries.

We replicated the same framework of the survey – i.e. its flow and questions – than what is presented in Burnay et al. (2016). The initial survey of Burnay et al. (2016) then served as a pre-test for the current study. The survey was quite short (around 5 min) and the participants could fulfill it online by their side. The survey is still available here[1] and is structured as follows:

- Step 0 — Language selection; Dutch, French or English.
- Step 1 — Introduce the context of the study; a study on creativity is conducted, where the data is explored to better grasp which qualities are associated with innovation.
- Step 2 — Collect basic demographic; age, gender, innovative behavior (how fast do you adopt innovative solution) and innovative experience. [Close ended questions; optional stage]
- Step 3 — The participant is asked to mention a solution (defined as *"a product, a service or an idea"*) they consider innovative (defined as *"being novel compared to other solutions available at the same time"*) alongside with a description and optional illustration. [Open ended questions; mandatory except the illustration]
- Step 4 — The participant is asked to mention one to five qualities that make them associate the solution to innovation. [Open ended questions; mandatory, at least one quality]
- Step 5 — The participant can visualize all previous answers reported by other participants by exploring real-time dashboards. Then, they are invited to submit other ideas (back to step 3) or leave the survey. We believe that presenting some solutions and qualities in the results inspired the respondents to submit more ideas.

4.1.2. Data processing

The objective of the data processing was to create clusters of similar qualities to reduce the list of qualities – collected with the survey – to the main aspects of innovation. It was possible with the use of the Wordnet taxonomy and we proceeded in three steps; (1) extract the noun from the collected qualities, (2) compute a *semantic similarity* measure between all nouns, (3) create *clusters* of similar qualities.

(1) Noun Extraction — The semantic similarity measure used in the next step only works between noun but we collected mostly adjectives with the survey. We first needed to extract the closest noun from any collected adjective, adjective satellite, verb or adverb. To that purpose, three strategies had been implemented and applied by trial and error using various linguistic tools. For the first strategy, we used Wordnet functionalities that allowed to return the *derivationally related form* or the *attribute*. If the first strategy failed, we applied nominalization rules. There are a number of syntactic rules that transform an adjective into a noun. For instance, most adjective ending with "able" (e.g. available) return a noun ending with "ability" (e.g. availability). When the second strategy failed, we extracted a noun by discarding the suffix of adjective; e.g. the adjective "comfortable" returns the noun "comfort". We sequentially applied the tools from the most general to the most specific one and the verification had been done using Wordnet.

(2) Similarity Matrix — With only nouns in the dataset, we were able to compute the semantic similarity between all nouns. We used the *Weighted Path Length* (Wpath) as a measure of semantic similarity (Zhu and Iglesias, 2017; Jia et al., 2018). The metric can be systematically processed between words thanks to the use of lexical taxonomy. In practice, the similarity metric is computed between two words and ranges from 0 to 1; 0 represents the maximum dissimilarity while 1 represents a perfect similarity. The metric is a weighted sum of three components. The first component is the *Path* technique which returns the shortest path length between the words and their Least Common Subsummer, i.e. their less abstract common ancestor. The second element is the Information Content (IC) graph-based which integrates the level of abstraction of the measured words in the metric. The third and last component is the IC corpus-based which incorporates statistical information of the words, i.e. a word occurrence and context analysis. Wpath has been created to rely on the benefits of well-known similarity metrics (such as *Path, Wup, Res, Lin Zhu and Iglesias, 2017*) but also to overcome their downsides thanks to its hybrid composition. Its performance over traditional similarity metrics has been demonstrated and evaluated (Ali and Rahman, 2018). The application of the Wpath measure had been done using *Sematch* Python library (Zhu and Iglesias, 2017) and produced a matrix whose columns and rows were the nouns of the dataset.

(3) Clusters — Once the similarity matrix produced, the next goal was to create groups of similar qualities, i.e. clusters. In order to adapt to the context of semantic similarity and very high dimensional space, we drew inspiration from the clustering method presented in Wagstaff et al. (2001). We applied the following clustering procedure:

1. Initialize a starting clustering configuration and identify C_j the center of each cluster j;
2. Iteratively adjust each center C_j and assign instances to the cluster of the closest center if any new:
   (a) Analyze the situation through visualizations or other tools;
   (b) Evaluate the situation (by either an error measure or by experts);
   (c) Go back to 2 until no further change
3. The point is to find k, the number of clusters, that produces relevant clusters. Analyze the relevance of the resulting clusters.

We followed this methodology systematically to build the algorithm. It was necessary to add to a traditional clustering approach the domain knowledge of the context to ensure relevant results from a linguistic perspective. We also ensured that the algorithm respected the clustering principles which are:

1. the similarity within a cluster is as high as possible, i.e. intra-cluster similarity;
2. the similarity between distinct clusters is as low as possible, i.e. inter-cluster similarity.

Based on the previous algorithm, the criterion that ultimately determined the number of clusters was a semantic similarity threshold. We started the initial configuration with a high value of the criterion; 0.8. The intra-cluster similarity was high respecting the first clustering. We then refined the clusters centers C_j by adjusting the criterion. We proceeded to this iterative process until we all were confident with the resulting clusters with respect to the clustering principles and to the methodology mentioned before. The clustering procedure had been defined and applied

[1] https://orsiam.unamur.be/triggers/content/InnovationSurvey-home.php

Fig. 3. Structure of a CT card.

with IT-experts while the resulting clusters had been validated in line with past observations on CTs with the initial authors of the CTs (Burnay et al., 2016).

4.1.3. Cards design

The baseline of the CTs is to create one card for illustrating one cluster (Burnay et al., 2016). To create the final set of cards, we used the design proposed and validated in Burnay et al. (2016) which builds a CT card on four sections as depicted in Fig. 3:

- The ***Title*** is the centroid of the clusters — i.e. the most representative element of the cluster. The centroid can be identified with the Wpath metric.
- All the other elements of the clusters are used for the ***Description*** and ***Consider Also To*** sections. They stand for presenting some thinking avenues.
- All qualities collected with the survey came with a product or service meaning that all member of a cluster has an associated solution. The most common solution associated to the members of a cluster is used for building the ***Example*** section that illustrates how a solution can share the quality, i.e. the title, of the card.

For each quality collected with the survey, we used the noun form for the data processing and the adjective form for the CT cards creation. The card design had been fulfilled with 3 researchers. The design had been cross-validated with the authors and with 6 external researchers to ensure the cards are understandable.

4.2. Results

4.2.1. Data collection

With the survey we reached 532 respondents. After discarding the non-recoverable responses (error, etc.), we ended up with a total of 1172 qualities reduced to 402 distinct qualities.

The sample heterogeneity had been monitored:

- 41% were women, 59% were men, all age ranges covered which the most frequent one was between 21 and 30 years old;
- There was a good mix of innovative experience among the sample — *no experience* (23%), *weak* (37%), *moderate* (35%) and *strong* (5%);
- Regarding the innovative behavior, the sample was mainly distributed between *Majority Followers* (36%), *Early Adopters* (33%) and *Late Adopters* (22%).

Table 2
The most similar words to *accessibility*.

Qualities	Accessibility
Accessibility	1.0
Convenience	0.891
Helpfulness	0.855
Availability	1.0

Table 3
The 4 first qualities of the similarity matrix.

Qualities	Cheapness	Smallness	Portability	Access
Cheapness	1.0	0.193	0.288	0.094
Smallness	0.193	1.0	0.193	0.103
Portability	0.288	0.193	1.0	0.094
Access	0.094	0.103	0.094	1.0

4.2.2. Data processing

(1) Noun Extraction – Initially, we had 402 distinct qualities including 226 nouns (i.e. "comfort", "performance", "control"), 168 adjectives/adverbs/verbs (i.e. "interactive", "modular", "healthy"), and 8 words that had not been found in Wordnet and we thus discarded them. The noun extraction algorithm was applied on the 168 qualities that were not a noun. It was quite effective since it successfully worked on 163 qualities while we manually handled the 5 remaining. During the extraction phase, some qualities returned the same closest noun. As a direct consequence, we ended up with 313 distinct nouns for the similarity matrix.

(2) Similarity Matrix – For each of these 313 nouns, we computed the Wpath metric to get its semantic similarity with all other nouns in the dataset. As a reminder, this metric ranges from 0 to 1, respectively from maximum dissimilarity to maximum similarity. For instance, some semantic similarity scores for the word "Accessibility" are reported in Table 2. Ultimately, we ended up with a symmetric matrix of 313 rows and 313 columns containing the semantic similarity between all qualities (Table 3).

(3) Clusters — The clustering procedure was applied on the similarity matrix and returned 22 clusters. For each cluster, the Wpath metric also returned its centroid which is the most representative member of the cluster. In technical terms, the centroid is the member of the cluster that has the highest similarity average with all other members of that very cluster. Table 4 presents the resulting clusters with their centroids.

4.2.3. Cards design

We ended-up this study with a final set of 22 Creativity Triggers cards. They are further detailed in this section. The full set of cards can be found in a repository (available here[2]) with material to use the Creativity Triggers.

We keep each card as simple as possible. Indeed, they must remain self-explanatory the keep the CTs a lightweight tool. Each cluster depicted in Table 4 represents one aspect of innovation and was illustrated by one card. With 22 clusters, we ended up with 22 cards; four of them are depicted by Fig. 4.

For each centroid, we retrieved its original form from which we extracted the nouns and this form ultimately became the card name. For instance, the centroid *uncommonness* of the 14th cluster (Table 4) was extracted from the initial quality *uncommon*. Ultimately, the name of the card is *uncommon* (and not *uncommonness*). The other members of the cluster are used in the other sections and are depicted in bold.

2 https://doi.org/10.6084/m9.figshare.19524841.v1

Table 4
Resulting clusters.

№	Clusters	Centroids
1	Smallness, size, slightness, parsimony	Smallness
2	Beauty, prettiness, attractiveness, desirableness, fascination, good	Attractiveness
3	Amusement, entertainment, delight, joy, excitement	Amusement
4	Ecology, environment, physiology	Ecology
5	Autonomy, independency, freedom	Independency
6	Change, effect, difference, intuition, smell, feeling	Feeling
7	Playfulness, fun, humor, wittiness	Humor
8	Originality, novelty, freshness, newness	Freshness
9	Application, technology, high-technology	Technology
10	Portability, mobility, movability	Movability
11	Shock, surprise, disruption, amazement	Surprise
12	Creativeness, imaginativeness, creativity, design, conception, creation	Conception
13	Sleekness, perfection, polish, smoothness	Polish
14	Singularity, unexpectedness, oddness, uncommonness, strangeness, unusualness, unfamiliarity	Uncommonness
15	Coherency, cohesion, connection, interconnection	Cohesion
16	Evolution, development, hobby, connector, involvement, engagement, communication, relevance	Involvement
17	Intelligibility, interest, power, powerfulness, effectiveness, clarity, color	Powerfulness
18	Convenience, easiness, usability, simplicity, helpfulness, availability, utility, accessibility, handiness	Accessibility
19	Comfort, comfortableness, facilitation, assistance, ease, relaxation, delivery, service, help	Comfort
20	Ingenuity, quality, cleverness, resources, superiority	Ingenuity
21	Cheapness, luxury, price	Price
22	Contemporaneousness, up-to-dateness, timing	Up-to-dateness

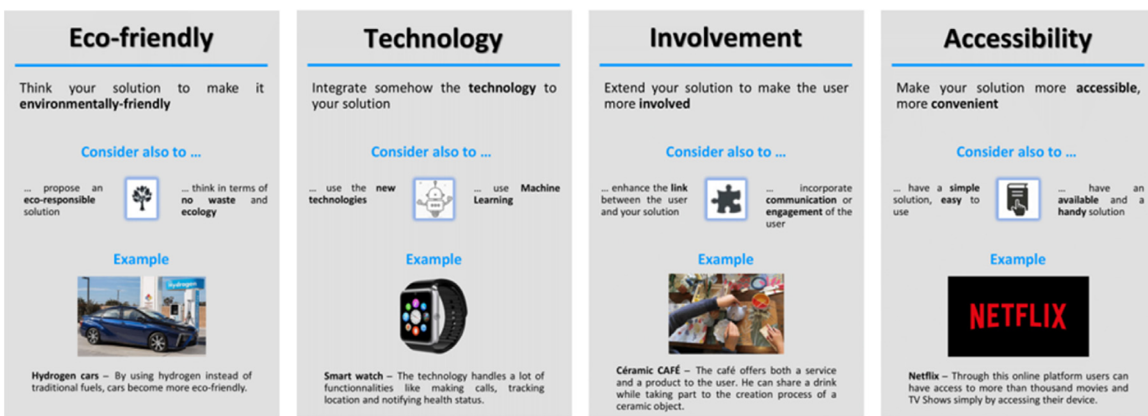

Fig. 4. 4 of the 22 Creativity Triggers cards.

5. Study 2: Feasibility study

In this second study, we evaluated the effectiveness of the proposed CTs in terms of their support for creative ideas generation. To do this, we asked three different types of stakeholders to use the CTs in a requirements process in order to assess the tool with different profiles. Each stakeholder type used the CTs in a different round of the RE process following the same experiment protocol.

In round 1, the stakeholder was a project sponsor – i.e. the person that decides to invest resources in the development of a new solution – and the case study was the launching of a new website. In round 2, the stakeholders were potential end-users – 19 Master students studying management sciences – and they were invited to work on a fictitious case, namely a cultural center which needed new ideas to attract more customers (see Appendix). In round 3, the stakeholder was a professional requirement engineer – 10 Business Analysts – which were also invited to work on the cultural center case (see Appendix). Table 5 gives an overview of the 3 rounds.

The main objective of this second study was to investigate the extent to which use of the CT tool led to the generation of more numerous and creative ideas. Data collected during the study was used to answer the following **RQ2 —** *does the CT tool contribute to more numerous and creative ideas during the elicitation phase of a RE process?*

5.1. Methodology

5.1.1. Experiment protocol

Each of the three rounds was organized following the same core procedure, with three different steps as depicted by Fig. 5. First, step 1 took place during which participants were invited to find ideas about a problem statement following traditional RE approach. Then, they were invited to uncover new ideas by using the CTs during step 2. Finally, we discussed with them to get some qualitative feedback and they had then to fulfill an online survey. Note that for any activity depicted here, the timings mentioned refer to the maximum amount of time needed by the teams. Fig. 6 and Fig. 7 respectively depict the underlying tasks of step 1 and step 2.

In *step 1, participants were invited to conduct a design task without CTs*. First, the real-world problem was introduced to participants (for instance, participants in round 3 were asked to resolve a situation where a Cultural center was lacking customer's interest). The overall objective was clearly exposed; find a solution, and do not be scared to "think outside the box". The material used for this step was then distributed to the participants. Finally, we led the step 1 elicitation. We led a traditional RE process of the corresponding project, adopting guidelines from RE Roadmap (Nuseibeh and Easterbrook, 2000). Concretely, the moderators gave guidelines to all participants while they worked in team from 4 to 5 participants – except for round 1 – to elicit

Table 5
Study 2 — Overview of the 3 rounds.

	Subjects	Viewpoint	Case
1	1 Entrepreneur	Sponsor	Real-word case — bank extranet
2	19 Master students	End-user	Fictitious case — cultural center
3	10 Business Analysts	Requirement Engineer	Fictitious case — cultural center

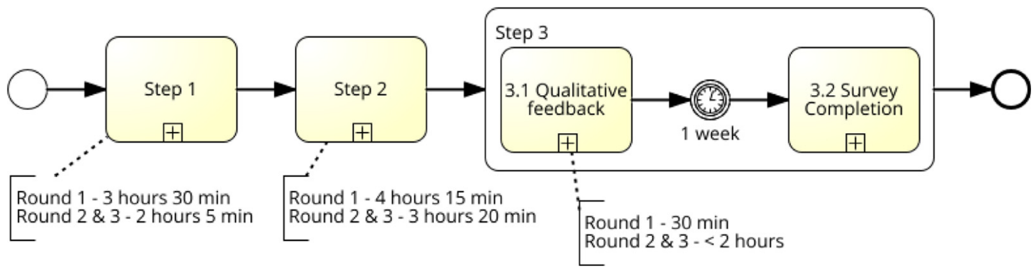

Fig. 5. Flow of the methodology — applied sequentially for the 3 rounds.

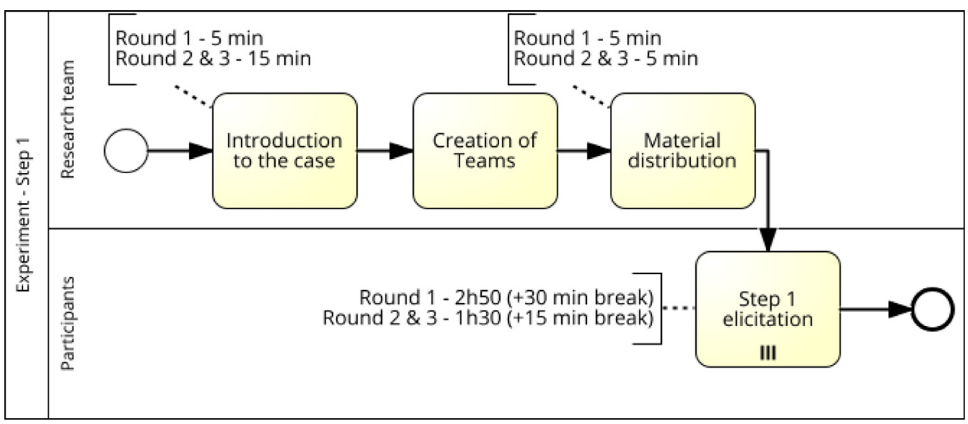

Fig. 6. Flow of step 1 — applied for the 3 rounds.

ideas. The moderators were experts in the RE field sometimes. Participants had a minimum time that they needed to dedicated to the task. After that minimum time, they had to stop when they felt having uncover all of their ideas. For that task we set a maximum time window to ensure the whole experiment did not take too much time affecting the fatigue of the participants. The flow of step 1 is depicted by Fig. 6.

In *step 2, participants were invited to think about the same problem as in step 1 with the help of CTs.* We first briefly introduced the CTs and the organization of step 2 to the participants. We then distributed the material for the current step. Finally the elicitation with CTs took place in team by applying the CTs protocol described in Section 3. We imposed the same minimum and maximum time duration and stopping condition for the elicitation of step 1 and 2. The flow of step 2 is presented by Fig. 7.

In *step 3, we invited participants to debrief and compare the ideas produced during step 1 and step 2.* We questioned participants to get qualitative feedback about the tool (e.g., Which of the triggers did you prefer and why? How did step 1 and step 2 work? What was easier/harder during step 2? How different was your thinking process from step 1 to step 2?). A survey was then submitted to participants a couple of days after step 2, in which all ideas from step 1 and step 2 were displayed randomly. Participants were then asked to tag any idea that they considered creative. We specified that "*creative ideas*" stood for "*the ideas that seem novel to the others and that seem the most appropriate to fight against competition*". Participants were also invited to define their top 3 ideas. To make sure the respondent had the necessary hindsight to be objective, we asked him to tag all ideas, even ideas from other teams. For data processing purposes, we then only selected the relevant tags.

5.1.2. Constructs

In order to answer our research question **RQ2** – *does the CT tool contribute to more numerous and creative ideas during the elicitation phase of a RE process?* – we identified outcome measures: (1) the relative *completeness* of the elicited ideas, in terms of the number of different ideas reported, (2) the *quality* of the elicited ideas, in terms of the novelty of the ideas reported and (3) the *degree of the adoption* of the tool, as reported by the different stakeholder types.

(1) Elicitation Completeness — This outcome measure captured the degree to which use of the CTs in step 2 allowed users to uncover ideas missed with earlier more traditional RE approaches in step 1. This refers to the *completeness* of elicitation which is an important and recognized problem in RE (Christel and Kang, 1992). If the CTs encouraged the users to uncover additional ideas, it is possible to conclude that the CTs supported the stakeholders to explore unknown parts of the problem and spaces. The measure was the number of unique ideas generated in each step.

(2) Elicitation Quality — This outcome measure captured the degree of creativity of the ideas generated in both steps. It was generated using the tags reported earlier to create a creativity score based on the percentage of stakeholders who considered an idea creative. For instance, if an idea received 8 creative tags out of 10 participants – meaning that 8 participants out of 10 considered the idea as creative –, then the creativity score is equal

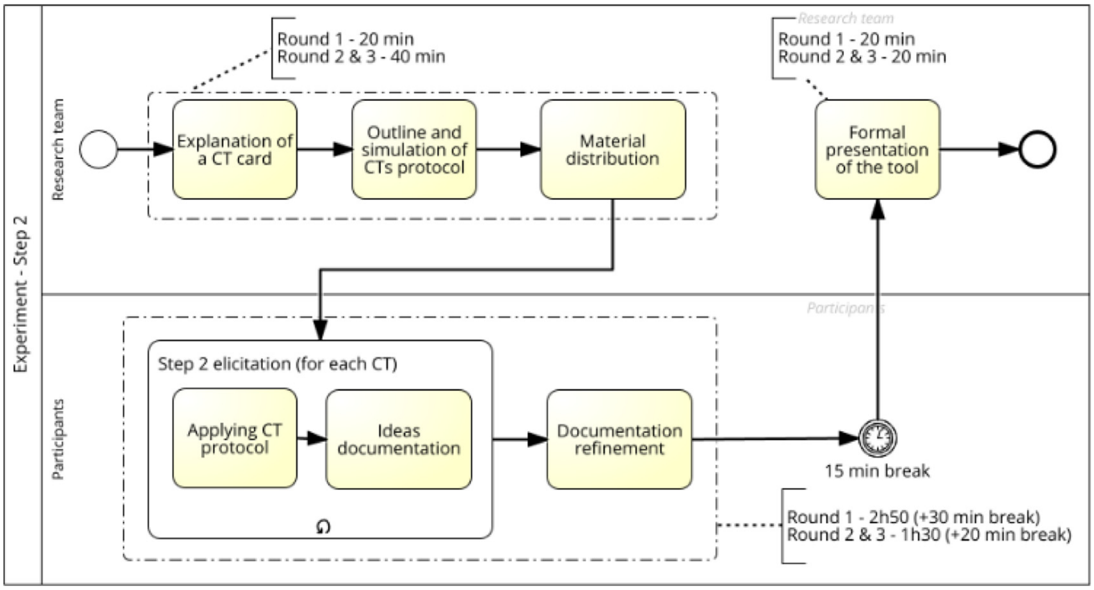

Fig. 7. Flow of step 2 — applied for the 3 rounds.

to 80%. Given that each team produced more than 1 idea, the creativity score of one team was the average of the scores of all ideas.

(3) Tool Adoption Willingness — This outcome measure captured the degree to which participants were supported by and able to use the CT tool to identify barriers and enablers to its adoption (España et al., 2010). Since this reflected on more qualitative but still very insightful aspects, this construct was assessed using semi-structured feedback given by the participants.

5.1.3. Data collection and analysis

Data collected and analyzed to determine these three measures were; (1) all data related to the produced ideas, (2) the creative tags applied to the ideas, and (3) the semi-structured feedback of participants.

Participants were asked to document all of the produced ideas on a spreadsheet that was then collected from them. The creative tags were collected using an online survey shared with the participants. The ideas and tags were associated, and to the different stakeholder and steps in each of the rounds in a simple relational database. This database enabled a systematic analysis of the data using a programming language. By contrast, the semi-structured feedback was collected from detailed written notes during a feedback session with the participants. This feedback was then analyzed by all experts involved in the experiment.

5.2. Results

Study 2 provided important and encouraging insights regarding the research question. For each construct, we present the result of Study 2.

5.2.1. Elicitation completeness

Results revealed that, in each of the three rounds, less than 50% of the total number of produced ideas were uncovered during step 1, see Fig. 8. In each round, with a different stakeholder type, the introduction of the CTs was associated with more than doubling the number of ideas generated with the more established RE approach.

In a general way, the tool seemed to help generate more ideas. The intuition was supported by one of the participants after they discovered the first ideas with the tool: *"When we start generating ideas [with the CTs], we then cannot stop"*.

5.2.2. Elicitation quality

We analyzed the ideas tagged by participants as creative or ranked as top 3. We wanted to assess the impact of the tool, on the creative aspect, for a given team from step 1 to step 2; did the tool allowed users to be more creative during step 2? This is the main reason why we only focused on tags given by a member of the team that generated the idea during the first step.

Fig. 9 depicts the quantity of ideas for each *creative rate range* by step for each round. As previously explained, this refers to the proportion of the team that gave a creative tag to a given idea. For instance, the blue bar *76-100%* for round 1 means that there are 7 ideas that are considered creative by 75 to 100% of the team during step 1 and round 1. Qualities with higher creative rate are then those for which the team agreed the most on their creative aspect.

Higher creative rate ranges then represent creative tags with a stronger power. In general, these ranges were higher for step 2 compared to step 1. This was especially striking by looking at the distributions of round 1 and round 2. On its side, the distribution of round 3 was more balanced; it seemed that ideas were more or less as creative during both steps. Regarding round 3, the first observation was that participants still succeeded to find new creative ideas during step 2 even if they had yet covered a lot of creative ideas during step 1. The point was not to strictly compare the creativity of step 1 against step 2 since they happened sequentially. The tool allowed to still find new ideas with the same creativity level which is valuable. The second observation was the intuition that the audience of round 3 was composed by creative people. This is supported by a participant saying: *"I found so many ideas during step 1, that it was hard to still find new one afterwards [during step 2] even if the tool helped me to find a few ones"* which was quite reassuring. Of course, this did not affect the relevancy of the tool. We expect that the CTs, by being a "tool", will be used by people who need it — i.e. people lacking creative thinking.

We then looked at the top 3 distributions proposed by Fig. 10. For each round, we collected the ideas that received a top 3 tag. After weighting by the number of participants, the figure presents the distribution of all top 3 ideas in percentage discriminated by the originating step of the idea. For all rounds, the percentage of step 2 was higher than the percentage of step 1. For instance, round 2 distribution showed that 59% of ideas considered as top 3 came from step 2. This reinforced the idea that the outcome of the tool was somehow creative.

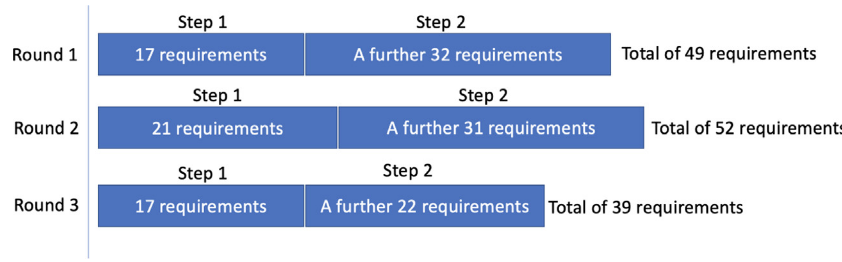

Fig. 8. Quantity of ideas produced during each step for all rounds/audiences.

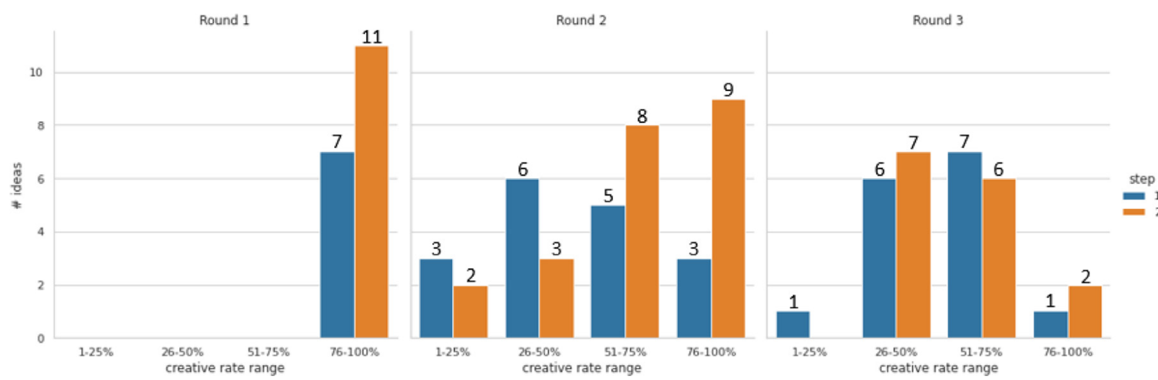

Fig. 9. Quantity of ideas by range of Creative Rate by step and rounds. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

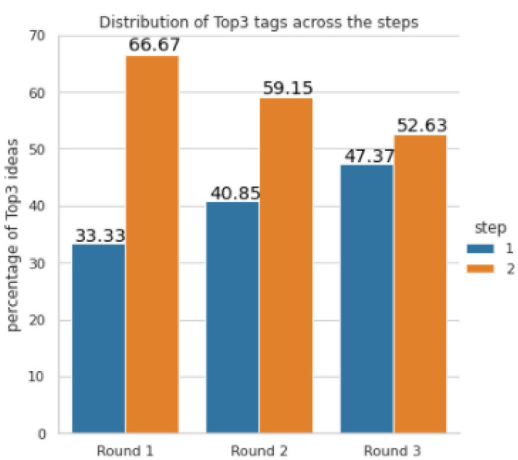

Fig. 10. Distribution of idea tagged as Top3 across the steps for all rounds.

5.2.3. Tool adoption willingness

In general, the feedback was positive. The tool was appreciated for its ability to guide the discussions and to open some avenues for further thinking. The tool was also valued for its ease of use and the absence of prerequisites to use it. In the first round, the CTs were confronted to the brainstorming technique: *"during past brainstorming, stakeholders sometimes did not have any idea and they were stuck without generating ideas. This downside seems to be overcome with the tool by its ability to set the direction of thinking"*. Regarding the cards, it was interesting to see that one card sometimes started the exploration of very different ideas which is strongly valuable for exploring the *unknown* in the problem/solution space. For instance, the card *Accessibility* was considered in two senses. First, it led to make the product accessible for color blind and hard of hearing people. Then, it led to make the system accessible everywhere through the use of mobile devices or offline mode. The conclusion is that the cards are not too specific and thus propose a broad range of thinking avenues. In Table 6, we summarize the main observations for the semi-structured questions and the unstructured feedback.

6. Discussions

The promising results of the reported work suggest numerous future research directions regarding creative thinking support. However, there were also limitations, and they need to be taken into account. In what follows, we present the future research directions and how we tried to mitigate the threats to validity in both studies that we led.

6.1. Future research

Future research could propose an *improved CTs cards design*. Indeed, the innovative qualities in this work have been collected by ensuring they have a kind of relevancy through time. The data collection survey proposed to the participants an open reflection about innovation in general, no matter the period of time. However, there is still some room for improving the design through other dimensions. First, we could dedicate efforts to studying why some triggers were more effective than others. Second, CTs revealed to be promising for both convergent and divergent thinking. We could inspect how their use or design could be adapted depending on the type of thinking that is targeted. All of this could be further explored to reach considerable milestones regarding the capability of the CTs to support creative thinking. It would contribute to propose a refined final set of CTs.

The second future work could analyze the link between the produced ideas and the card that produced it to find out if there are repeating pattern in all the content produced by the same card. Each idea comes from a quality, i.e. the card's name, which could somehow refers to a *Non-Functional Requirement* (NFR) (Chung et al., 2012). On the other side, the generated ideas are never very far from a *Functional Requirement* (FR) (Chung et al., 2012). We could work on all ideas generated by a quality

Table 6
Qualitative feedback summary.

Questions	Participants' answers	Observations
(i) *Which of the three triggers did you prefer and why?*	(1) *"I cannot explain why but some cards, like "feeling", was easier for me. I directly thought of concrete ideas."*	Regarding the cards, some of them were preferred over others essentially because some cards sounded more meaningful to some participants, namely the card *cohesion*, *accessibility*, *feeling* and *independence*.
(ii) *What was easier/harder during step 2*	(1) *"[It was easier because] the card forced us to focus on one aspect at a time [the card name]. At the same time, it was more difficult since we had to think to an imposed topic".* (2) *"Thanks to the cards we got help to focus on the "what" and thus find new ideas. However we were less supported on the "how" to effectively implement the "what".* (3) *"We were lacking ideas during step 2 because we elicited a lot of ideas during the first step. We finally came with few new ideas but we think we have discovered a lot of ideas during the first stage".* (4) *"As it generates a lot of ideas, the exploration of each idea is more general. Some requirements need further deepening. It can be interesting to couple the CTs with other techniques."*	Broadly speaking the majority of respondent thought step 2 was easier with the tool. (2) is very relevant since the business case was focused on generating idea as an Early-Phase (Yu, 2002). We believe that the ideas generated with the tool must be afterwards formally documented, like any RE process, to further investigate them. It would allow to focus on the most promising ideas and to elaborate on the "how". (3) did not surprised us a lot as explained before. This specific team has probably more creative skills by nature.
(iii) *How different was your thinking process from step 1 to step 2?*	(1) *"The difference between both stages was obvious, at least to me. I was more challenged with the tool and I was more comfortable to find ideas".* (2) *"The second step was more detailed than the first one. The Triggers allowed to develop more precisely an idea".* (3) *"I think the name of the tool is well adapted. When using the tool, I really felt that I had a trigger that gave me food for thought".* (4) *"I had issues with organizing the ideas [during step 2]. The tool creates a lot of ideas and the outcome is thus less structured. It is then necessary to sort the ideas and to review them. However, the tool does not give any support for that."*	For many, the difference between step 1 and step 2 was radical. Step 2 revealed more comfortable for many what regards ideas generation. As direct consequences, that had to face many produced ideas and the challenge of structuring them. (4) Led us to think about the ability of the tool to support convergent thinking (refer to Section 3).
(iv) No specific question/free talk with participants	(1) *"There is no barrier with the use of the tool. The tool may even be used without a specific leader."* (2) *"The tool generates ideas with a great scope maximising the number of topics that are reviewed during elicitation."* (3) *"In opposite to brainstorming, the effectiveness of the tool depends less on the people by giving concrete support and directions."*	Additional remarks made by the participants after the semi-structured interviews.

to investigate the link between FRs and NFRs in this specific case. Does it give insight on how some NFRs can be implemented by FRs? What are the commonalities shared by the generated ideas of the same cards?

Another direction of future research consists in an *automated and digital version of CTs*. More precisely, the focus is to deliver the CTs to requirements engineers as a digital rather than manual tool, and to use capabilities associated with digital creativity support tools to stimulate creative thinking about requirements further. A first version of a prototype of this digital tool is now available. With this prototype, a team of requirements engineers can upload an English-language text corpus (e.g. a problem description, a set of requirements, or just idea descriptions) and select one of more creative qualities of interest to the team. Each quality is associated to a different creativity trigger. The prototype then invokes different natural-language parsing and sense-making algorithms to extract themes from the entered text corpus, and uses these themes to generate different 'Think about' statements based on the selected qualities/creativity triggers. Unlike the current manual card, this automatic generation of instantiated creativity triggers – itself an example of combinational creative thinking – has the potential to generate multiple statements that are novel but still potentially valuable to requirements engineers, leading to more ideation. Early user testing of the prototype revealed that presenting the more general 'Think about' statement with up to 3 statements describing examples of how ideas might be generated was the most effective. We look forward to reporting on this prototype development in future publications.

The fourth future research may focus on the maintenance of the tool. The objective of the current study was to propose a final version of the tool whose design is complete and utility demonstrated. Now that it is the case, we should focus on how to ensure the maintenance of the tool in a straightforward and partially automated way. For instance, we could think to an automated generation of the example shown on the card to keep them up-to-date.

Finally, in Burnay et al. (2016), they plan to design a *sharing creativity platform* to centralize feedback and experience around the Creativity Triggers. This platform is not yet designed but the ambition is still relevant so we plan to contribute to it. The goals of the platform would be multiple. First of all, it would give access to the tool and the works already done about the Creativity Triggers. Secondly, it would be a means to gather experiences around the tool and to effectively evaluate it with greater scope. Finally, the platform would be a meeting point to exchange around the incorporation of Creativity in the Requirement Engineering; an aspect that is recognized by authors as more and more crucial.

6.2. Threats to validity — Study 1

This study is the empirical part of our work. Just like any empirical work, the study is subject to some validity threats (Wohlin et al., 2012).

One threat to *conclusion validity* (Wohlin et al., 2012) is the fact that respondents may not have paid enough attention while answering the survey. This threat is reduced by the cleaning of the data (in order to discard irrelevant answers) and by the design of the online survey. We made it interactive to better involve the participant in our study. Another treat is the *Reliability of measures* (Wohlin et al., 2012). Indeed, the quality of the data manipulation highly depends on the Wpath metrics (Zhu and Iglesias, 2017) since it is the factor on which two qualities are considered (dis)similar. A lot of researches have already been done what regards the semantic similarity of words. Although the Wpath metric seems the best similarity metric that can be found up to now, it can still be enhanced. We have therefore tried to mitigate its downsides thanks to the input of the experts.

The obvious threat to *internal validity* is the *Testing* (Wohlin et al., 2012) meaning that the answer to a question can be biased if the respondent had already been confronted with the question before. In our work, the respondent can answer the survey multiple times. If they had already submitted one form, they can make a new one by submitting a quality they previously saw in the results part of the survey. We would then collect the quality multiple times wrongly increasing its importance. However, the threat is not relevant in our case since we only focused on the fact that the respondent considers the quality as innovative, no matter if the quality comes from his mind or not.

Finally, there are threats to the conclusions generalizability; the *external validity* (Wohlin et al., 2012). We tried to decrease these threats as much as possible. First, we increased the amount of data compared to what is done in Burnay et al. (2016). Second, our sample was not restricted to people with specific characteristics. We believe that it is enough heterogeneous. For that purpose, we controlled some variables like the creativity experience and behavior, the respondent country, etc.

6.3. Threats to validity — Study 2

This study is the evaluation part of our work which is also subject to validity threats discussed below.

The main threat to *conclusion validity* (Wohlin et al., 2012) is the excessive heterogeneity. We compensated it by choosing 3 separated audiences; different audiences had different backgrounds (contributing to sample heterogeneity), while the background was more or less the same within a given audience (contributing to sample homogeneity).

The first threat to *internal validity* is the *Diffusion or imitation of treatments* (Wohlin et al., 2012). If participants are fully aware that we will analyze the creative side of their ideas, they may force themselves to be creative biasing their natural behavior. In order to reduce this, we presented the case progressively without neither anticipating the next steps nor talking too much about creativity. However, this could be done to a limited extent since the name of the tool contains the word "creativity". The second threat is the number of subject that varies from one audience to another. On the one hand, we weighted some of our results to take into account this variation. On the other hand, we did not directly confronted the results of two different audiences. We most and foremost compared the results of two steps of the same audience.

One threat to the *construct validity* is the *Experimenter expectancies* (Wohlin et al., 2012). In order to prevent results that are led by conscious or unconscious expectations from the experimenters, we integrated some unstructured feedback during which participants were able to freely talk about the tool, i.e. without being biased by structured questions. This feedback allowed to contradict or to reinforce observations made with the structured questions. Another threat is participants that did not pay enough attention while experimenting. We offset this threat with the composition of the audiences; they were voluntary participants that felt comfortable with the experiment setting. Another threat lies in the fact that ideas reported in step 2 were generated because of reasons other than the CT tool. One possible reason was learning about the problem domain, i.e., the stakeholders were still learning about the problem domain between step 1 and step 2. However, the time between the steps was short – less than 30 min – in each round, so we believe that the impact of a learning effect was minimal. In the overall duration of a requirements process, 30 min is an almost insignificant amount of time. Furthermore, the stopping event for both steps was a saturation condition — participants continued each step until learning ceased and ideas were reported to more complete. Indeed, our analysis suggests that step 2 ideas could have been discovered during step 1, but the participants did not due a lack of support to explore the unknown. More importantly, many of the ideas generated in step 2 could be associated with the CT card themes used to generate the ideas. The last threats to construct validity is the possible fatigue effect which could negatively affect the experiment results and especially both elicitation phases. However, participants had a lot of breaks and we frequently asked them for any issues. Notice that the timing of the elicitation phases was the maximum amount of time. It means that the teams which took that maximum timing were teams that decided themselves to keep going with the activity.

The last threats affect the *external validity* (Wohlin et al., 2012). The first one is the use of students as participants that must be controlled (Svahnberg et al., 2008). We targeted Masters-level students, i.e. fourth-year students, close to an internship and job market, to balance this threat. This is also alleviated by the audience that was not exclusively composed by students. The second threat is the use of a fictitious case that was necessary to fit the background of all audiences. We balanced this by proposing a case close to a real one; the workflow was realistic and the issues were trendy and inspired from real ones.

7. Conclusion

Creativity is nowadays crucial for any organization to compete with novel solutions. Therefore, the need for lightweight tools that support creative thinking has become apparent. This also holds for Requirement Engineering. To this purpose, Burnay et al. (2016) proposed a creative tool for RE; the *Creativity Triggers* (CTs). In this paper, we extended the early exploratory work of Burnay et al. (2016) in order to lead further research around the CTs. We proceeded with two studies.

In Study 1, we did the creation process of the Creativity Triggers again to propose an enhanced version of the tool. We followed the same methodology employed in Burnay et al. (2016) to extend its findings and to improve on the limitations. We were able to collect more data increasing the representativeness of the tool. We then proceeded to an advanced clustering by ensuring the final outcome was relevant to clustering principles, to linguistic theories and to the objective of the CTs initially presented in Burnay et al. (2016). As a result, 22 Creativity Triggers have been proposed increasing their completeness.

Study 2 intended to evaluate the tool with three realistic case studies including 3 audiences (with different backgrounds), 3 different professional viewpoints and 30 participants. With the data and feedback collected, we assessed the CTs capabilities in supporting creative thinking. This assessment had been done along 3 axes: first, the ability of the tool to uncover numerous ideas, i.e. the quantity; second, the quality of the produced ideas regarding their creative essence, i.e. the quality; third, the convenience when using the tool. All things considered, the tool proved to be valuable along the three axes. The main conclusion, that was shared by all rounds, was the ability of the tool to frame and to guide the discussion, to give avenues for thinking. This ability allows to avoid situations where stakeholders are stuck without generating ideas and overcomes the blank page syndrome. This observation reinforces the fact that the tool effectively plays the role of a *trigger*.

On the one side, this work proposes a ready-to-use version of the CTs that effectively support creative thinking in RE. On the other side, this led us to identify some new aspects that may be interesting to explore. We did not investigate them since there were out of our scope. However, if proven relevant in the future, they can be opportunities to lead further researches around the Creativity Triggers.

CRediT authorship contribution statement

Benito Giunta: Conceptualization, Software, Data curation, Investigation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Corentin Burnay:** Conceptualization, Investigation, Formal analysis, Methodology, Resources, Writing – original draft, Writing – review & editing. **Neil Maiden:** Conceptualization, Investigation, Formal analysis, Validation, Writing – review & editing. **Stéphane Faulkner:** Resources, Project administration, Validation, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix. Fictitious case statement

"A cultural centre in town is offering various services to its clients, namely: theatre/concert halls, conferences, an art gallery and a café. The cultural centre is facing business issues. The alternative activities (cinema, sports, gaming, …) are harsh competitors and customers become rare. The customer's interest in culture is decreasing and the café offering is too similar to what you can find in other cafés. As a stakeholder, you have to find new ideas to rescue the business. What would you suggest?"

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