Article V

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An experimental comparison of using cause-effect diagrams and simple memos in software project retrospectives

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Abstract

Root cause analysis (RCA) is a recommended practice in retrospectives and cause-effect diagram (CED) is a commonly recommended technique for RCA. Our objective is to evaluate whether CED improves the outcome of RCA and the perceptions of retrospective participants. We conducted a controlled experiment with eleven student software project teams by using two-by-two crossover design resulting in total of 22 experimental units. Two visualization techniques of underlying causes were compared: CED and a simple memo, i.e. a structural list of causes. We used the output of RCA, questionnaires, and group interviews in order to compare the two techniques. CED increased the total number of causes with medium effect size. CED also increased the links between causes, thus, suggesting more structured analysis of problems. Furthermore, the participants perceived that CED improved organizing and outlining the detected causes. The implication of our results is that using CED in the RCA of retrospectives is recommended, yet, not mandatory as the groups also performed quite well with the structural list. CED is visually more attractive and more effective than the structural list, but it is somewhat harder to read and requires specific software tools increasing the burden of adaptability.

Key words: Root Cause Analysis, Retrospective, Post Mortem Analysis, Cause-Effect Diagram, Controlled Experiment

1. Introduction

Root cause analysis (RCA) is used in software project retrospectives, which are recommended practice for example in the Scrum software development method (Schwaber and Sutherland 2011). In retrospectives, individuals work together in order to create an understanding of what worked well in the prior project, and what could be improved (Bjørnson, Wang, and Arisholm 2009). RCA helps in capturing the lessons learned from individuals (Lehtinen, Mäntylä, and Vanhanen 2011) and aims to state what the perceived problem causes are and where they occur (Lehtinen and Mäntylä 2011; Lehtinen et al. 2014a). Furthermore, RCA can be a part of project retrospectives, but it can also be a part of continuous software process optimization as recommended by the CMMI model (Software Engineering Institute 2010).

A cause-effect diagram (CED) is a commonly recommended technique for RCA (Bjørnson, Wang, and Arisholm 2009; Lehtinen, Mäntylä, and Vanhanen 2011; Anbari, Carayannis, and Voetsch 2008; Dingsøyr 2005). The diagram is used to register and visualize the outcome of RCA, i.e., the underlying causes of the problem. Its objective is to ease the detection and communication of the underlying causes and their causal structures. However, there are no studies comparing the use of CED with the use of simple memos which represent the most straight-forward approach to documenting retrospectives as they require no special tools, i.e., a word processor or just a pencil and paper is enough. The use of simple memos can be thought as a natural baseline, which graphical diagrams, such as the CED, should be compared with. In our previous work, we operated with software organizations that have used simple memos about the problems instead of CEDs (Lehtinen, Mäntylä, and Vanhanen 2011; Lehtinen et al. 2014b). Thus, reporting and visualizing the causal structures of a problem do not necessarily require CED and the benefits of CED have not been investigated in previous work.

Our research problem is the following: *Is CED really needed in the RCA of software project retrospectives, and if so, why?* To contribute to the research problem we organized a controlled student experiment as part of a software engineering capstone project course, where students conduct software projects in industrial like environment. We

compared the outcome of RCA and the perceptions of retrospective participants between a CED and a structural list technique.

The rest of the paper is structured as follows. Section 2 introduces the related work, which includes using RCA in the retrospectives of software projects. Additionally, we will present how the CED and structural list techniques can be used in RCA to visualize and organize the causes of problems. At the end of the section, gaps in the existing research are presented. Section 3 presents the research objectives, questions, and methods. We will also introduce the research context, research hypotheses, the used retrospective method (Bjørnson, Wang, and Arisholm 2009) and the experiment design including the treatments, response variables, and controlling the undesired variation. Section 4 presents the study results. Furthermore, we will answer the research questions and discuss the validity threats in Section 5. Section 6 summarizes our findings and suggests future work on the topic.

2. Related work

We start this section by presenting the concept of RCA in retrospectives. Thereafter, Section 2.2 introduces CED techniques which are commonly recommended in RCA. Thereafter, Section 2.3 presents the structural list technique which is claimed useful in order to detect the causes of problems during RCA. Section 2.4 concludes the gap in the research.

2.1. Root cause analysis of retrospectives

Retrospectives are aimed to facilitate learning from occurred problems. In retrospectives, the team members use RCA to detect the underlying causes for the detected problems. At the beginning of retrospectives, the team members list problems they have faced during the project or milestone (Bjørnson, Wang, and Arisholm 2009). Thereafter, the team members select important problems to be further analyzed with RCA (Bjørnson, Wang, and Arisholm 2009). Next, the causes of the problems are detected (Bjørnson, Wang, and Arisholm 2009). This can be done by constantly asking "why?" for every cause detected (Lehtinen, Mäntylä, and Vanhanen 2011), e.g., by using Five Whys technique (Andersen and Fagerhaug 2006). While the causes are detected, they are organized into CED (Bjørnson, Wang, and Arisholm 2009). The ultimate output of RCA is the causal structure of problems (Lehtinen et al. 2014a; Stålhane et al. 2003).

Software project retrospectives have been introduced as synchronous face-to-face meetings (Dingsøyr 2005; Dingsøyr, Moe, and Nytrø 2001), but today's company practices seem to favor distributed settings (Terzakis 2011). Respectively, CEDs have been introduced as useful for retrospectives (Bjørnson, Wang, and Arisholm 2009), but the existing company practices seem to favor simple memos (Lehtinen, Mäntylä, and Vanhanen 2011; Lehtinen et al. 2014b). Software tool support for collaborative cause-effect diagramming is also missing (Lehtinen et al. 2014b) and therefore conducting RCA in distributed settings is currently challenging by using the methods introduced in prior studies (Stålhane et al. 2003). Thus, in terms of the tool support, we should determine how to visualize the outcome of RCA.

2.2. Cause-effect diagrams

Cause-effect diagrams are the most frequently used techniques in RCA. They are commonly used to register and visualize the causal structures of problems. Various techniques to draw CED are introduced, e.g., a fishbone diagram (Andersen and Fagerhaug 2006; Burnstein 2003; Stevenson 2005; Ishikawa 1990), a fault tree diagram (Andersen and Fagerhaug 2006), a directed graph (Bjørnson, Wang, and Arisholm 2009), a matrix diagram (Nakashima et al. 1999), a scatter chart (Andersen and Fagerhaug 2006), a logic tree (Latino and Latino 2006), and a causal factor chart (Rooney and Vanden Heuvel 2004). However, only few of them are utilized in the retrospectives of software projects. These include the fishbone diagram (Bjørnson, Wang, and Arisholm 2009; Andersen and Fagerhaug 2006; Stålhane et al. 2003; Burnstein 2003; Stevenson 2005; Stålhane 2004) and directed graph (Bjørnson, Wang, and Arisholm 2009; Lehtinen, Mäntylä, and Vanhanen 2011; Lehtinen et al. 2014b). The fishbone diagram applies a tree structure where the causes of problems are organized into some premade classes of causes (Lehtinen, Mäntylä, and Vanhanen 2011). Instead, the directed graph applies a network structure where the causes of problems are organized solely based on their cause and effect relationships (Lehtinen, Mäntylä, and Vanhanen 2011).

In the context of software project retrospectives, the use of the fishbone diagram has been compared with the directed graph (Bjørnson, Wang, and Arisholm 2009). It has been claimed that the directed graph outperforms the fishbone diagram (Bjørnson, Wang, and Arisholm 2009). This means that the outcome of RCA is at least somewhat dependent on the technique used to visualize the causes of problems. The directed graph increases the number of detected causes (Bjørnson, Wang, and Arisholm 2009). It also improves the analysis by increasing the number of

hubs, which are defined as causes that are related to more than one problem (Bjørnson, Wang, and Arisholm 2009). The strict hierarchical manner and weak layout of the fishbone diagram is one its main weaknesses (Bjørnson, Wang, and Arisholm 2009). Another problem of the fishbone diagram is the tree structure (Lehtinen, Mäntylä, and Vanhanen 2011). The tree structure creates a problem of duplicating the same cause under many effects whereas in the network structure only references to the effects are duplicated (Lehtinen, Mäntylä, and Vanhanen 2011). Thus, in the network structure, the number of cause statements remains as low as possible.

2.3. Structural lists

A structural list is an alternative approach of CED. It is used to register and visualize the causal structures of problems as simple memos, i.e. textual notations, of problems, including the representation of causes and their effects. Ammerman (1998) presented a technique for RCA called Causal Factor List. He claims that listing the causes into a computer file helps in detecting the root causes of problems. Drawing CED requires writing down cause statements with graphical nodes and edges to interconnect the detected causes (Dingsøyr, Moe, and Nytrø 2001). Instead, listing the causes requires only that the cause statements are written down and simultaneously placed under one another. Additionally, making a structural list of causes does not require specific software tools for RCA as it is with CEDs (Lehtinen, Mäntylä, and Vanhanen 2011; Lehtinen et al. 2014b). Thus, it can be easily adapted to distributed software project retrospectives where the participants are geographically distributed, a research problem introduced by Stålhane et al. (Stålhane et al. 2003).

Furthermore, the retrospective outcome and the perceptions of participants utilizing a structural list have rarely been compared with the use of CED (Stålhane et al. 2003; Stålhane 2004). In our prior study (Lehtinen, Mäntylä, and Vanhanen 2011), we criticized the feasibility of using the structural list technique in RCA. We claimed that in the context of software engineering, using that technique makes the analysis difficult, because of the high number of detected causes (Lehtinen, Mäntylä, and Vanhanen 2011). However, our conclusions were mostly based on assumptions. Instead, the structural list has the same practical problem as the fishbone diagram; when a cause explains more than one effect, you need to place the same cause under many effects. This means that while using the structural list in RCA, the workload actually increases as now you need to write down causes more than once (Lehtinen, Mäntylä, and Vanhanen 2011). However, comparison between the fishbone diagram and the directed graph (Bjørnson, Wang, and Arisholm 2009) is not enough for determining the effectiveness of using the structural list, because the fishbone diagram utilizes different visual structure than the structural list.

2.4. Gap in the research

The prior studies have failed to address the questions whether the use of CED outperforms simple memos formulated as a structural list (Ammerman 1998) during the RCA of retrospectives. Instead, the prior studies have indicated that the effectiveness of RCA is dependent on the technique used to visualize the causes of problems (Bjørnson, Wang, and Arisholm 2009; Lehtinen, Mäntylä, and Vanhanen 2011). Yet, those studies compare two different visualization techniques rather than comparing CEDs directly with the simple memos. Comparison to simple memos is important as the memos are the most straight-forward to use and they are used in industry (Lehtinen, Mäntylä, and Vanhanen 2011; Lehtinen et al. 2014b). Making memos does not require drawing nodes and arrows between the causes of problems as it is with CEDs. Therefore, they neither require specific software tools (Lehtinen, Mäntylä, and Vanhanen 2011; Lehtinen et al. 2014b). Thus, it is possible that a memo in the form of a structural list is a more effective technique than using CED. The results of Ottensooser et al. (Ottensooser et al. 2012) who compared the use of textual and graphical notations for interpreting business process descriptions support this idea. On the other hand, it is also possible that it is precisely the arrows and nodes of CEDs which improve the retrospective outcome and the perceptions of participants as they help to visualize the causal structures of problems. The prior studies on organizational learning systems and “cognitive maps” support this view (Lee, Courtney, and O'Keefe 1992).

3. Research methods

In this section, we introduce the research goals and present how the research data was collected and analyzed in this controlled experiment (Juristo and Moreno 2003). Research objectives and questions are introduced in Section 3.1. Thereafter, the research context is presented in Section 3.2. In Section 3.3, we introduce the experimental design including the used retrospective method and the treatments, response variables and controlling the undesired variation. Section 3.4 introduces the data collection and analysis methods.

3.1. Research objectives and questions

Our objective is to *evaluate whether CED improves the outcome of RCA and the perceptions of retrospective participants when compared with writing down a structural list about the causes of problems analyzed in software project retrospectives*. The comparison is based on two cause and effect structuring techniques, i.e., *a directed graph* (Bjørnson, Wang, and Arisholm 2009; Lehtinen, Mäntylä, and Vanhanen 2011) and *a structural list* (Ammerman 1998). Based on the prior studies in the context of software projects (Bjørnson, Wang, and Arisholm 2009; Lehtinen, Mäntylä, and Vanhanen 2011), the directed graph is claimed as the most optimal CED technique in the RCA of retrospectives. We compare the number and causal structures of detected causes considering both the total number of causes and the number of causes with specific characteristics. We also compare the perceptions of participants about the techniques. The research aims to answer the following comparative questions:

RQ1: Is there a difference between the techniques in terms of the outcome of RCA?
- *RQ1a: Is there a difference in the number of the detected causes?*
- RQ1b*: Is there a difference in the structures of the detected causes?*
- *RQ1c: Is there a difference in the characteristics of the detected causes?*

RQ2: Is there a difference between the techniques in terms of the perceptions of retrospective participants?
- RQ2a*: Is there a difference in the preferred technique?*
- RQ2b*: How do the retrospective participants evaluate and describe the techniques?*

3.2. Research context

Since the early 1980s, Aalto University has provided a capstone project course for computer science students (Vanhanen, Lehtinen, and Lassenius 2012). During the course, the students develop software for external customers in teams. The software development for each customer is arranged as a software project lasting for five months. Each student uses approximately 150 hours for the project. Based on our experiences and the course feedback, the students are highly committed to the projects. The project teams have a total of seven to nine student members. These include a project manager, a quality manager, a software architect and four to six developers. There are no freshmen students in the course. The managers are M.Sc. level students whereas the developers are B.Sc. level students. Many students already have years of experience on industrial software development.

The teams are required to follow a process framework defined by the course. The process framework divides the projects into three timeboxed *iterations*, each lasting six to seven weeks. The process framework combines practices from both agile and plan-driven process models. These can be adapted to sprints, iteration planning, iteration demos, backlogs, weekly stand-ups, retrospectives, pair-programming, continuous integration, risk management, effort estimation and realization, use-cases, test-case based functional testing, and more rigorous quality assurance. Each team is responsible for planning and using a development process that follows the process framework. (Vanhanen, Lehtinen, and Lassenius 2012)

The use of students as study subjects has been discussed in the software engineering literature, e.g., (Svahnberg, Aurum, and Wohlin 2008; Berander 2004; Carver et al. 2003; Runeson 2003; Höst, Regnell, and Wohlin 2000). Runeson (2003) discussed the difference of using freshmen students, graduate level students, and industry personnel as study subjects. The conclusions are that graduate level students are feasible subjects for revealing improvement trends, but infeasible to reveal the absolute levels of improvements (Runeson 2003). Berander (2004) explained that the applicability of using students as study subjects is dependent on their experience and commitment. He also claims that the use of students "as representatives for professionals" is more appropriate in software projects than classroom settings (Berander 2004). Similar conclusions are also given by Carver et al. (2003).

The experiment was conducted in the retrospectives of eleven project teams out of fourteen during the academic year 2010-2011. The participation in the experiment was voluntary for the project teams. The team members did not know the objective of the experiment in advance. The research context was feasible for studying the improvement trend over the use of CED and structural list in the software project retrospectives of small teams. Most of the student subjects were graduate level students, who were experienced on software development and committed to their software projects. Thus, in the retrospectives, they were able to consider software project problems, which were relevant to their teams. The course projects were also similar to "real" projects. Thus, many challenges faced by the student teams were industrially relevant, as we concluded in our prior study (Vanhanen, Lehtinen, and Lassenius 2012). These included challenges related to team building, team members, project requirements, project management, and quality assurance. The customers were also committed to their projects and they paid a fee for the university when they got a student project. Thus, the students were required to develop software that was truly

needed by the customers. Additionally, similar research context has been previously used to conduct somewhat similar comparison (Bjørnson, Wang, and Arisholm 2009).

3.3. Experiment design

For the participating project teams (see Section 3.2), we provided the retrospective methodologies and controlled the retrospective settings. The course framework required the teams to conduct a retrospective at the end of the second and third iteration. The retrospective method and the used effort were fixed (see Section 0). Thus, our design had two experimental units (retrospectives) for each participating project team, meaning 22 experimental units as a total.

The experiment followed a single factor paired design with a single blocking variable (Juristo and Moreno 2003). The factor that we examined was the technique used to visualize and organize the causes of problems. The factor had two alternatives: CED and a structural list. Both of these treatments were applied by each team, but in different retrospectives starting with a randomized order. Figure 1 introduces the CED and Figure 2 introduces the structural list technique. In CED, arrows are drawn between the causes of the problem. Instead, in the structural list, the causal structure is visualized using bullet lists. Furthermore, if a cause affects more than one effect, multiple arrows are drawn from the cause when using CED (see causes 8 and 16). Instead, with the structural list such cause needs to be duplicated under each effect it explains.

The blocking variable that we were not able to eliminate was the project phase where the retrospectives were conducted. The first retrospective was conducted in the middle (Iteration 2) and the second was conducted at the end of the project (Iteration 3). We balanced our experiment design in order to take the project phase into account in the analysis. Table 1 summarizes the experiment design including the distribution of teams in the treatments and the project phase. The starting order of treatments was randomized for each team. As a result, six teams used CED and five teams used the structural list in the first retrospective (Iteration 2). Respectively, six teams used the structural list and five teams used CED in the second retrospective (Iteration 3). This randomization balanced the potential effects of the blocking variable related to the project phase. Furthermore, our data analyses were conducted as a paired analysis comparing the differences of the treatments inside each team, which mitigates the effects of differences between teams.

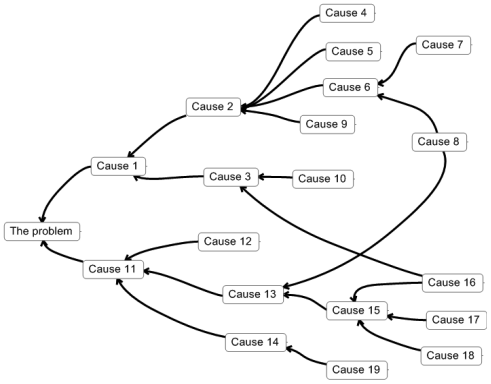


Figure 1. The CED technique

The Problem
- Cause 1
  - Cause 2
    - Cause 4
    - Cause 5
    - Cause 6
      - Cause 7
      - Cause 8
    - Cause 9
  - Cause 3
    - Cause 10
    - Cause 16
- Cause 11
  - Cause 12
  - Cause 13
    - Cause 8
    - Cause 15
      - Cause 16
      - Cause 17
      - Cause 18
  - Cause 14
    - Cause 19

Figure 2. The structural list technique

Table 1
Distribution of treatments (A=CED, B= the structural list) into 22 experimental units

		Team (T)										
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
Phase (I)	I2	A	A	B	A	A	A	B	B	B	A	B
	I3	B	B	A	B	B	B	A	A	A	B	A

3.3.1. Retrospective method

The used retrospective method, summarized in Figure 3, started with a short introduction about the method. We presented for the participants how the steps of Problem Detection and Root Cause Analysis will be conducted in the retrospective. Our method follows the postmortem analysis method introduced by Bjørnson et al. (2009) who

claimed that such a retrospective method is lightweight and feasible for small software project teams. The method consists of two separated steps, which are introduced below.

In the first step (Problem Detection), the participants were asked to write down problems, which have had a negative impact on reaching the project goals. Thereafter, each participant introduced the problems to the others. The problems were registered and projected on the wall by the first author who acted as a scribe. Similar problems were grouped together by the participants. Thereafter, the participants voted two problems for RCA. The first step was timeboxed to about 30 minutes.

The second step (Root Cause Analysis) was conducted for both of the voted problems separately, lasting 40 minutes for each problem. First, each participant alone wrote down causes for the voted problem (5 minutes). Thereafter, they presented the causes for the others who simultaneously brainstormed more causes (15 minutes). The facilitator registered all detected causes immediately to a cause and effect structure shown on the wall. These two phases were repeated once more for the same voted problem. The second voted problem was thereafter processed.

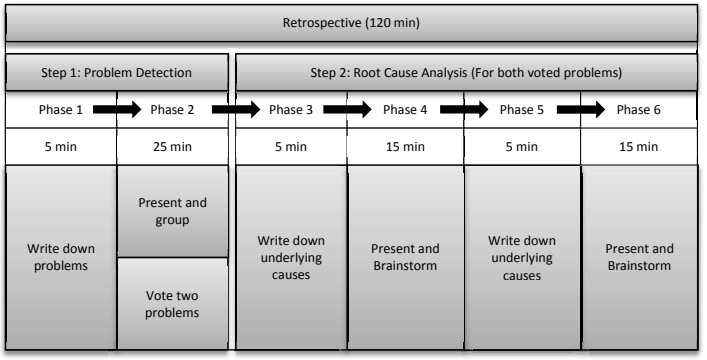


Figure 3. The retrospective method used in the study

3.3.2. Response variables and research hypothesis

Figure 4 introduces the taxonomy used to clarify our research hypotheses. The figure draws a simple *causal structure* for a problem. The problem is placed on the left side of the figure while its causes are placed on the right side. The causes are organized based on their cause and effect relationships. Theoretically, each cause creates an *effect* (or *effects*), which itself can be a cause or the problem, and it is affected by its *sub-cause(s)*. In the figure, the causes being placed next to the problem are the effects of their sub-causes placed on the right side of the diagram. In order to simplify our terminology, each cause, effect and sub-cause explaining why the problem occurs is *a cause of the problem*.

Furthermore, our terminology introduces a term *depth level*, which indicates the shortest distance from the cause to the problem. The distance quantifies the number of causes at the causal structure from the cause to the problem. Additionally, *size of a depth level* indicates the number of causes organized to the same depth level. We can see that the size of the Depth Level 1 is 2. Finally, *a hub cause* (Bjørnson, Wang, and Arisholm 2009) refers to a cause that affects more than one effect and *a single cause* refers to a cause that affects exactly one effect.

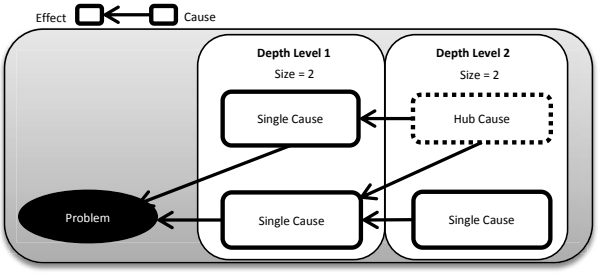


Figure 4. Taxonomy used to clarify our research hypotheses

Table 2 summarizes the response variables, our research hypotheses, and the measurements that we used. It has been claimed that the more problem causes are detected, the more effective is the retrospective method (Bjørnson, Wang, and Arisholm 2009). In the terminology of this paper, the response variable called *method effectiveness* (ME) indicates the number of problem causes detected. It is a simple indicator that counts the numbers of causes detected while ignoring their actual content and related causal structures. For example, there are 19 causes in Figures 1 and 2. Thus, the ME would be *19* for both figures. Our hypothesis was that the retrospective method utilizing CED results in a higher ME than the one utilizing the structural list. We based this hypothesis on prior studies that have commonly recommended using CEDs in RCA (see Section 2.2).

Causal structure indicates the cause and effect structure of the causes of the problem. There are two response variables related to the causal structure, i.e., the *size of depth level* (Bjørnson, Wang, and Arisholm 2009) (SoDL) and the *number of hub causes* (Bjørnson, Wang, and Arisholm 2009) (NoH) (see Figure 4). The function SoDL(x) indicates the number of causes being registered to the depth level x, whereas the NoH value indicates the number of detected causes which explain more than one effect. Our hypothesis was that generally the return value of SoDL(x) increases among the depth levels. This hypothesis was based on our prior experiences on the output of RCA in industrial software project context (Lehtinen and Mäntylä 2011). In RCA, the detection of causes starts by the detection of few "first level causes" (Andersen and Fagerhaug 2006), which thereafter evolve to the detection of "higher level causes" (Andersen and Fagerhaug 2006) resulting in increasing number of detected problems and causes at the higher depth levels. We also hypothesized that the return value of SoDL(x) increases more with CED than with the structural list. This hypothesis was based on our understanding about the visual structure of CED. In contrast to the structural list, CED uses graphical nodes and edges (see Figure 1) helping the participants to focus on the detected causes. Additionally, CED utilizes network structure which maintains the causal structure as clean and simple. Thus, we assumed that higher numbers of causes are detected at the higher depth levels when CED is used. The return value of SoDL(x) is measured by calculating the number of causes at the corresponding depth level x.

Furthermore, our hypothesis was that the NoH value is higher when CED is used. In CED, arrows are drawn between the cause and its effects. Instead, in the structural list, the cause needs to be duplicated under the effects it explains. Thus, the number of cause statements is lower in CED than it is in the equivalent structural list. Therefore, there is less distraction in the causal structure when CED is used and thus it is likely that it is easier to detect the different effects the cause explains. We think that the more there are hub causes, the more extensively the causal relationships are analyzed. This is because the hub causes create interconnections between larger ensembles of causes than interconnections between few individual causes. The NoH value is measured by calculating the percentage of causes that were used to explain more than one effect.

Characteristics of detected causes (CDC) indicate the distribution of the detected causes among process areas and cause types. Our hypothesis was that the CDC is not dependent on the treatments. We based this hypothesis on the fact that neither of the treatments steers the participants to consider some specific project areas or cause types. We believed that the CDC was mostly dependent on the teams and problems analyzed, not on the studied techniques used to organize and visualize the problems and their causes. CDC is measured by using a classification system for the detected causes. We compared the distributions of causes in cause classes over the treatments.

Perceptions of participants (PP) reflect the evaluations of the participants on the treatments. Considering the PP, our initial hypothesis was that the participants prefer CED to be used in retrospectives. This hypothesis was based on prior studies that have commonly recommended using CEDs in RCA (see Section 2.2). We used a questionnaire (see Appendix 1) after each retrospective to measure the perceptions of participants. Additionally, after both treatments were conducted, we used another questionnaire (see Appendix 2) combined with a group interview in order to conclude which treatment the participants preferred and why.

Table 2
Response variables, research hypotheses, and related measurements used

Response Variable	**Research Hypothesis**	**Measurement**
Method Effectiveness (ME)	ME with Diagram > ME with List	The number of causes
Causal Structure		
Size of Depth Levels (SoDL)	SoDL(n+1) > SoDL(n) >…> SoDL(2) > SoDL(1)	The number of causes at different depth levels
	$\frac{\text{SoDL}(n+1) \text{ with Diagram}}{\text{SoDL}(n+1) \text{ with List}} > 1$	The number of causes at different depth levels
Number of Hub causes (NoH)	NoH with Diagram > NoH with List	The percentage of causes that were used to explain more than one effect
Characteristics of Detected Causes (CDC)	CDC with Diagram ≈ CDC with List	Distributions of classified causes
Perceptions of Participants (PP)	PP with Diagram > PP with List	Questionnaires and group interviews

3.3.3. Controlling undesired variation

We assumed that it was highly possible that the project phase where the retrospective was conducted had an impact on the retrospective outcome. We also assumed that the retrospective outcome is highly dependent on the team. In order to balance the effects of these variables, the treatment of each team was randomly assigned in the first phase. In addition, we applied both treatments to each team and used paired analysis to mitigate the variations between teams.

We ensured that the retrospective settings were similar in each experimental unit. Therefore, six context variables were controlled. The context variables included the retrospective goal, the number and roles of the participants, the used language, the physical settings, and the retrospective facilitator. We also identified and measured three confounding variables, since we had no control organizing the teams and the project topics. The confounding variables included the voted problems (see Section 0), team members' motivation, and team spirit.

We controlled the goal of each retrospective. This was important as the problems related to software projects and the number and characteristics of their underlying causes vary (Lehtinen and Mäntylä 2011). Thus, our study results were dependent on the problems analyzed. We controlled this issue by forcing each team to analyze a common endemic problem that occurs frequently during the projects, i.e. "*why it is challenging to reach the project goals*" (Vanhanen, Lehtinen, and Lassenius 2012).

The number and roles of retrospective participants were controlled. This was important as we believe that the number and causal structures of the causes of a problem are dependent on the number of participants. A high deviation in the number of participants between the treatments would likely have biased the study results. We decided that each retrospective has to include at least four to seven participants, as suggested in (Lehtinen, Mäntylä, and Vanhanen 2011). Additionally, the maximum deviation in the number of participants between the two retrospectives of each team was limited to +/- 1. Similarly, the roles of the participants were controlled. It was decided that at least two out of three people in the management roles of the team have to be present at both retrospectives.

The used language was controlled. This was important as we believe that the team members' contribution is dependent on the language used. People are likely more active speakers when they use their own mother tongue and thus also the output of retrospectives is dependent on the language used. It was decided that the teams have to use the same language in both treatments.

Every retrospective was conducted in similar physical conditions. We took care that the infrastructure used to register and visualize the problems and their causes did not change between the retrospectives, i.e., the used laptop, software tools (Mindjet and MS Word) and projector. This was important as the screen resolution, margins, zoom level, etc. could have otherwise biased the study results through varying visualization capabilities. Similarly, the meeting room settings including the room size, lighting and location remained similar.

We also controlled the facilitator of the retrospectives. The first author of this paper steered each retrospective and acted as the scribe for each team. This was important as thus we were able to control the skills of the facilitator. The first author has prior experiences on steering RCA and he was also familiar with the used software tools.

Three confounding variables were measured in order to evaluate that dramatic changes in the working of the team did not happen between the retrospectives. The confounding variables included the voted problems (see Section 0), team members' motivation and team spirit. Considering the voted problems, we compared the problems the retrospective participants selected for RCA in each treatment. This was important as now we were able to evaluate whether the differences in the treatments may have been caused by different problems analyzed. Furthermore, considering the team members' motivation and team spirit, we used a questionnaire after each retrospective, as introduced in Section 3.4.3. This was also important as now we were able to evaluate whether the differences between the treatments were caused by varying motivation or team spirit. We asked the participants to evaluate their personal effort, their team's effort, the openness in communication, and the team spirit in each retrospective. We also asked them to evaluate 1) whether some participants purposefully left some important causes out of their attention and 2) whether the participants did not dare to name all the detected causes publicly.

3.4. Data collection and analysis

In this section, we introduce the methods we used in the data collection and analysis. As a summary, the data collection was based on triangulation which increases the validity of the study results (Yin 1994; Runeson and Höst 2008; Jick 1979). We used the output of RCA in statistical analyses on the method effectiveness and causal structures of the treatments (see Section 3.4.1). Additionally, we used the output of RCA to analyze whether the characteristics of detected causes remained similar over the treatments (see Section 3.4.2). Furthermore, we combined statistical methods with qualitative methods in order to evaluate the perceptions of participants about the

treatments. We asked the participants to provide feedback by using questionnaires (see Section 3.4.3) and group interviews (see Section 3.4.4). Each retrospective and group interview was video recorded in order to be able to transcribe the interviews and further analyze the retrospectives if needed.

3.4.1. Method effectiveness and causal structures

The method effectiveness was analyzed with the paired-samples two-tailed t-test with the alpha level 0.05. We compared the number of detected causes in the retrospectives of each team. Each cause was counted only once, i.e., the duplicate cause statements were removed. As the number of retrospective participants varied +/-1, we also compared the number of detected causes per number of participants. We also analyzed the method effectiveness by comparing the average, minimum, lower quartile, median, upper quartile, and maximum number of detected causes between the treatments.

The causal structures were analyzed by comparing the size of depth levels, and the number of hub causes between the treatments. In the comparison, we used the paired-samples two-tailed t-test with the alpha level 0.05. Between the treatments of each team, we analyzed whether CED results systematically in larger sizes of depth levels than the structural list technique. Furthermore, we also analyzed whether CED systematically results in a larger proportion of hub causes.

Using the t-test was reasonable as the number of detected causes in the treatments was normally distributed between the teams. This conclusion was based on the Shapiro-Wilk test and the analysis of related Q-Q plots. We also tested that the distributions of causes at depth levels were normally distributed. The number of causes was normally distributed from the first to sixth depth levels.

Furthermore, we evaluated the standardized effect size for the systematic differences between the treatments by using Cohen's d (Cohen 1988). This was done by dividing the difference between the means of treatments with their pooled standard deviation. The effect size results were interpreted in the following way: $d < 0.2$ (small), $d \approx 0.5$ (medium), and $d > 0.8$ (large) (Cohen 1988). The following pattern was used to calculate Cohen's d, where X_i is the sample mean, n_i is the sample size, and s_i is the standard deviation (Kampenes et al. 2007):

$$Cohen's\ d = \frac{X_1 - X_2}{\sqrt{\frac{(n_1 {s_1}^2 + n_2 {s_2}^2)}{(n_1 + n_2)}}}$$

3.4.2. Characteristics of detected causes

We evaluated the characteristics of each detected cause (there were a total of 2247 causes) in order to evaluate whether the causes of problems detected in the retrospectives of each team remained similar between the treatments. We classified the detected causes by using a classification system developed for analyzing the characteristics of the causes of software project problems introduced in our prior studies (Lehtinen and Mäntylä 2011; Lehtinen et al. 2014a). The classification system divides the causes based on their types and process areas. In the classification system, a process area (a total of 6 process area variables) expresses where the cause occurs (see Table 3) whereas a cause type (a total of 14 cause types variables) describes what the cause is (Lehtinen and Mäntylä 2011) (see Table 4). The combination of the process area with the cause type results in *a characteristic of the cause* (a total of 6 x 14 = 84 characteristics). For example, if the cause is classified into the *management work* process area and its type is classified as *values & responsibility*, the characteristic of the cause is *values & responsibility in the management work*.

In order to evaluate whether the characteristics of the causes were similar between the treatments, we calculated the correlation between the numbers of causes with the same characteristic over the treatments. The correlation was calculated between the treatments of each team and between all teams combined together. The closer the correlation is to 1, the more similar are the characteristics.

3.4.3. Data from questionnaires

The analyses on the perceptions of participants were partially based on questionnaires. Questionnaire 1 (see Appendix 1) was used for both treatments separately. Our aim was to evaluate whether similar parts of the treatments were evaluated similarly. We also evaluated whether different parts of the treatments, i.e. the technique used to organize and visualize the causes, were evaluated differently. Furthermore, after the second retrospective, the participants were asked to compare the treatments by using Questionnaire 2 (see Appendix 2). Our aim was to evaluate which treatment the participants prefer the most in the RCA of retrospectives.

Questionnaire 1 included 19 questions covering all phases of the retrospective method. We asked the participants to evaluate the method used to collect the causes of problems. We also asked them to evaluate the method used to

Table 3
Process areas of the classification system express where the causes occur (Lehtinen and Mäntylä 2011)

Process Area	General characterization of the detected causes
Management Work (MA)	Company support and the way the project stakeholders are managed and allocated to tasks.
Sales & Requirements (S&R)	Requirements and input from customers.
Implementation Work (IM)	The design and implementation of features including defect fixing.
Software Testing (ST)	Test design, execution, and reporting.
Release & Deployment (PD)	Releasing and deploying the product.
Unknown (UN)	Causes that cannot be focused on any specific process area.

Table 4
Cause types of the classification system express what the causes are (Lehtinen and Mäntylä 2011)

Type / Sub-type	General characterization of the detected causes
People (P)	This cause type includes the people related causes
Instructions & Experiences	Missing or inaccurate documentation and lack of individual experience.
Values & responsibilities	Bad attitude and lack of taking responsibility.
Cooperation	Inactive, inaccurate, or missing communication.
Company Policies	Not following the company policies.
Tasks (T)	This cause type includes the task related causes
Task Output	Low quality task output.
Task Difficulty	The task requires too much effort, or time, or it is highly challenging.
Task Priority	Missing, wrong, or too low task priority.
Methods (M)	This cause type includes the methodological causes
Work Practices	Missing or inadequate work practices.
Process	The process model is missing, unclear, vague, too heavy, or inadequate.
Monitoring	Lack of monitoring.
Environment (E)	This cause type includes the environment related causes
Existing Product	Complex or badly implemented existing product.
Resources & Schedules	Wrong resources and schedules.
Tools	Missing or insufficient tools.
Customers & Users	Customers' and users' expectations and need.

organize the causes. Additionally, the questions included statements about the treatments which the participants were supposed to either agree or disagree with. The scale in each question was ordinal and symmetric, e.g., 1=very bad, 2, 3, 4=neutral, 5, 6, 7=very good. We assumed that the evaluations on the treatments vary only in the specific questions about the method used to organize the causes. This was due to the fact that the causes were organized differently, but collected similarly in both treatments (see Section 0). We compared the treatments by using the Wilcoxon Signed Rank Test with alpha level 0.05 over the evaluations of individual respondents. We also used the Bonferroni correction to calculate the required level of statistical significance. There were a total of 19 questionnaire items. Therefore, the Bonferroni correction gives that the level of statistical significance requires $p = 0.0026$ (0.05/19). The evaluations of participants who were not present at both retrospectives (10 of 61 participants) were excluded from the comparison.

Questionnaire 2 included statements about both retrospectives which the participants were asked to either agree or disagree with. The statements compared the treatments. The scale of the questionnaire was ordinal and symmetric (1=fully disagree, 2, 3, 4=neutral, 5, 6, 7=fully agree). We compared the share of participants who disagreed with the statements to those who agreed with them. The evaluations of participants who were not present at both retrospectives (10 of 61 participants) were excluded from the comparison.

3.4.4. Data from group interviews

In order to consolidate the results from the questionnaires and create a deeper understanding about the perceptions of participants in both treatments, we carried out a group interview with each participating team after the second retrospective. The interview took place immediately after the participants had answered the questionnaires. We did not want to focus the interviews on any specific questions. Instead, we wanted to create an understanding on what the participants thought about the treatments on a general level. The group interview was open ended (Yin 1994) and it was started by asking *"which of the used techniques do you prefer the most in the RCA of*

retrospectives?" Thereafter, depending on the answers of the participants, the interviewer (the first author) asked clarifying questions about the treatments, e.g., *"why do you prefer the structural list as a more feasible technique?"*

The interviews were transcribed and thereafter coded by the first author. Additionally, the interviews were translated into English. After the interviews were transcribed into a literal form, the interviews were carefully scrutinized. Thereafter, we created categories that conceptualized the comments of the participants. The first author created preliminary categories, which were thereafter reviewed by other authors.

Open coding technique (Flick 2006) was used to analyze how the participants described the treatments. As suggested in (Flick 2006), we started the qualitative analysis by recognizing "the units of meaning", i.e. concepts that reflected the reasoning given in the comments (single words and short sentences of words from the comments). For example, there was a comment *"with CED it is easier to outline the aggregation of causes"*. This comment resulted in a concept: "supports outlining aggregations". Similar concepts were grouped together. Thereafter, all comments were attached to the concepts.

The comments were classified line-by-line to the concepts we recognized, as recommended in (Flick 2006). Simultaneously, the comments were divided between the treatments. Thus, we were able to compare how the participants described the treatments on the conceptualized level. In order to compare the comments on a more abstract level, we continued the analysis procedure by recognizing categories that linked the concepts together (Flick 2006). This was done by pondering the potential meaning of concepts for retrospectives. For example, we assumed that the concepts "supports outlining aggregations" and "supports thinking" would affect the sense making while the participants try to understand the causes of problems in retrospectives. Thus, a category "sense making" was created and the corresponding concepts were linked under it.

The treatments were compared based on the categories and concepts that we recognized. We compared the treatments in order to recognize the concepts that were unique and common for the treatments. This helped us to make comparison and generalize how the treatments were described, which thereafter helped us to make hypotheses about the study results considering the method effectiveness and causal structures, too. Additionally, this helped us in interpreting the evaluation results from the questionnaires. Furthermore, we also compared the number of groups and comments on the related concepts. This was also somewhat important as it indicated the commonality of the perceptions of participants.

4. Results

In this section, we present the study results. We start in Section 4.1 by introducing the quantitative results on the output of the treatments. These include the comparison of the method effectiveness, causal structures, and characteristics of detected causes. Thereafter, in Section 4.2, we introduce how the participants evaluated and described the treatments.

4.1. Output of root cause analysis

In this section, we present the results regarding the output of RCA when applying the two alternative treatments. Table 5 summarizes the retrospectives of each team. It shows that the specific focus of the retrospectives remained mostly similar in each team.

Table 5
Statistics about the retrospectives

Team	CED						SL					
	#	L	Voted problems	∑p	∑c	c/p	#	L	Voted problems	∑p	∑c	c/p
1	1	F	Co-operation, management	5	76	15	2	F	Co-operation, management	4	70	18
2	1	F	Scope, quality	7	87	15	2	F	Quality, scope	6	59	10
3	2	E	Scope, development	5	93	19	1	E	Co-operation, management	6	78	13
4	1	F	Scope, quality	6	127	21	2	F	Quality, scope	5	85	17
5	1	F	Co-operation, customer	6	137	23	2	F	Quality, customer	6	92	15
6	1	F	Tasks, motivation	5	121	24	2	F	Motivation, skills	5	137	27
7	2	F	Scope, task monitoring	5	111	22	1	F	Task monitoring, scope	6	98	16
8	2	E	Process, skills	6	109	18	1	E	Process, skills	6	97	16
9	2	F	Management, co-operation	5	129	26	1	F	Co-operation, management	5	125	25
10	1	E	Requirements, risk management	6	69	12	2	E	Requirements, skills	6	90	15
11	2	F	Co-operation, management	5	113	23	1	F	Co-operation, management	6	100	17
			Mean	6	107	20			Mean	6	94	17

#=indicates whether the treatment was conducted in the first (1) or second (2) retrospective, L=used language (F=Finnish, E=English), ∑p=the number of participants, ∑c=the number of detected causes, c/p=the average number of detected causes per participant

4.1.1. Method effectiveness

Table 6 presents the descriptive statistics of the number of detected causes divided into the treatments. These include the average (Mean), standard deviation (Std), minimum (Min), lower quartile (Q1), median (Med), upper quartile (Q3), and maximum (Max). The table views the statistics from the team and individual levels. The team level compares the treatments by using the number of detected causes in each team. Instead, the individual level compares the treatments by using the average number of detected causes per participants in each team. Figure 5 draws the boxplots for the number of causes at the team level and Figure 6 presents the boxplots for the average number of detected causes per participants.

The descriptive statistics indicate that CED outperformed the structural list (SL) in the method effectiveness (see Table 6, and Figures 5 and 6). CED resulted in 107 detected causes as an average. Respectively, the structural list resulted in 94 detected causes. The mean difference and the 95% confidence interval are 12.8 and ±13.8, respectively. The effect size between the treatments is medium (Cohen's d=0.57, p=0.065). When analyzing the method effectiveness on the team level, CED outperformed the structural list in 9 out of 11 teams (see Table 5 for details).

When we normalize the number of detected causes by the number of participants, we find that in CED the average number of detected causes per participant was 19.8 compared with 17.2 in the structural list. The mean difference and the 95% confidence interval are 2.5 and ±2.69, respectively. The effect size is medium (Cohen's d=0.52, p=0.065). Furthermore, when analyzing the average number of detected causes per number of participants in a team, CED outperformed the structural list in 8 out of 11 teams (see Table 5 for details).

Thus, whether or not we normalize for the number of participants CED provides a medium effect size in number of detected causes (Cohen's d=0.57 or d=0.52), but the difference is not statistically significant (alpha p=0.05) due to small sample size (n=22).

Table 6
Descriptive statistics of the number of detected causes between the treatments

Focus	Treatment	Mean	Std.	Min	Q1	Med	Q3	Max
Team	SL	94	22	59	82	92	99	137
	CED	107	22	69	90	111	124	137
Individual	SL	17	5	10	15	16	17	27
	CED	20	4	12	17	21	23	26

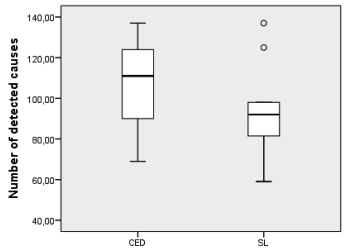


Figure 5. Boxplot of the number of causes in the treatments

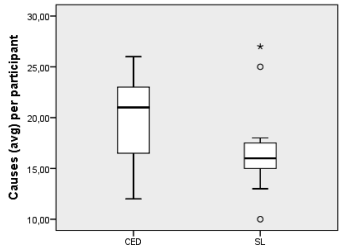
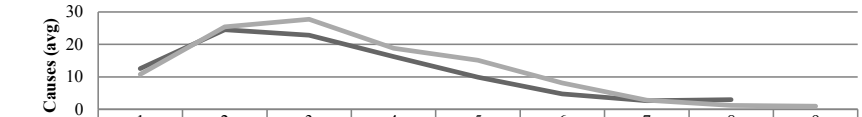


Figure 6. Boxplot of the average number of causes per participant in the treatments

4.1.2. Causal structures

Considering the causal structures, Figure 7 shows the average size of the depth levels (SoDL), see Section 3.3.2. With CED, the SoDL increases between the first and third depth levels. Instead, with the structural list the SoDL increases only between the first and second depth levels. The differences between the treatments in the size of the first (p=0.293, Cohen's d=-0.51) and second (p=0.811, Cohen's d=0.12) depth levels are not statistically significant. The effect sizes are medium to small, respectively. Instead, the difference in the size of the depth level three is statistically significant (p=0.020) and the effect size is large (Cohen's d=1.01). Thus, it is possible that CED allows creating causal structures that have more causes starting from the third level than ones created with the structural list. The difference in the total amount of the detected causes summed from the third to last depth level is medium (Cohen's d=0.64, p=0.07). However, the differences between the treatments in the number of the detected causes at the later depth levels (four to nine) are not statistically significant.

Figure 8 presents a boxplot of the percentage of hub causes (NoH) in both treatments (a cause that explains more than one effect, see Section 3.3.2). While comparing the total number of hub causes between the treatments, the t-test gives a large and significant difference (p=0.010, Cohen's d=1.42). As an average, 7% (std. 3%) of the detected causes were hub causes when CED was used. Instead, the average number of hub causes was only 3% (std. 2%) when the structural list was used.



	1	2	3	4	5	6	7	8	9
SL	13	25	23	16	10	5	3	3	
CED	11	25	28	19	15	8	3	1	1

Causes (avg) at Depth Levels (1-9)

Figure 7. Summary of the average number of causes (a total of 2247 detected causes) at depth levels (a total of nine depth levels)

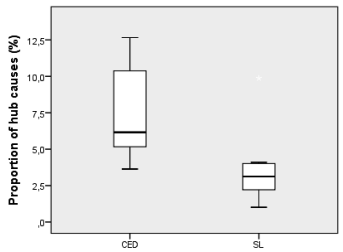


Figure 8. Boxplot of the share (%) of hub causes from all detected causes in the treatments

4.1.3. Characteristics of detected causes

Figure 9 indicates that similar causes were detected in both treatments. For example, in both treatments the top cause was the output of management work (n=106 for the structural list, n=107 for CED). The figure compares the characteristics of all detected causes (see Section 3.4.2) divided between the treatments. Based on the number of causes with similar characteristics, the data is organized from the highest to the lowest number of characteristics occurred in CED.

Figure 10 has the same data as Figure 9 and it illustrates the linear correlation of the number of causes with the same characteristics between the treatments. Each plot in Figure 10 represents the number of causes with the same characteristic in both treatments. The X-axis shows the number of causes with a certain characteristic of the structural list and the Y-axis shows the number of causes with the same characteristic of CED. The shares of detected causes with similar characteristics correlate strongly between the treatments (Pearson's r=0.896, p<0.001). This means that the characteristics of the detected causes did not depend significantly on the treatments.

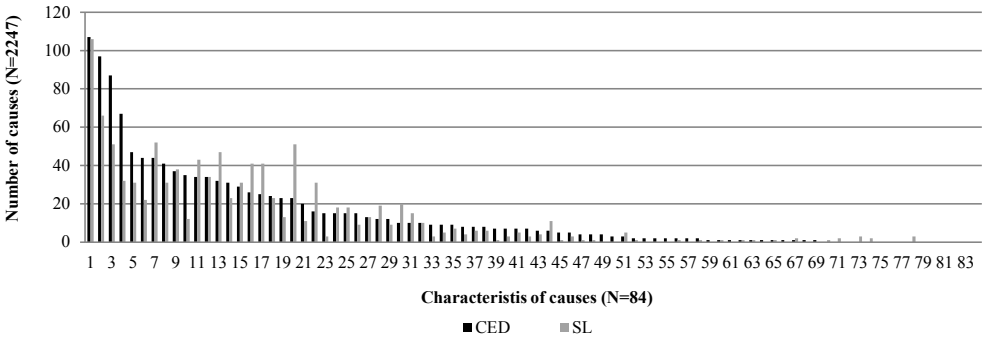


Figure 9. Distribution of causes among their characteristics

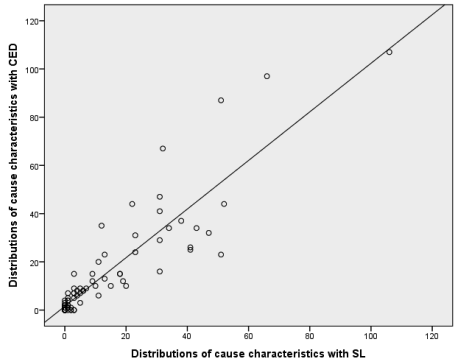


Figure 10. Linear correlation on the distributions of cause characteristics between the treatments
(A plot in the figure represents the same cause characteristic with both treatments)

4.2. Feedback of participants

In this section, we present the analysis of the most relevant questionnaire data in terms of the research questions. Next, we present the participant's evaluations on the methods after each treatment, their comparisons on the two treatments as well as the findings from the group interviews.

4.2.1. Evaluations after each treatment

Table 7 summarizes the results from Questionnaire 1 that had four Topics. This questionnaire was given after both the first and second retrospective. For both treatments, the evaluations were highly similar considering how the causes of problems were collected, i.e. Topic 1. Furthermore, no differences were detected in Topic 3, the general usefulness of the retrospective, or in Topic 4 that measured the social atmosphere of the retrospective.

Topic 2 of the survey studied how the detected causes were organized and in there we found some differences between the methods. The participants preferred CED when asked about the *technique used to organize the causes* (see Table 7, ID 2.1) and Wilcoxon Signed Rank Test (WSRT) showed that the difference between the treatments is highly statistically significant (p=0.001). The participants also thought that getting the "big picture of the problem causes" was easier with CED (see Table 7, ID 2.2). However, the difference is not statistically significant (WSRT p=0.089). Finally, the participants saw no difference between treatments in the easiness to register problem causes (see Table 7, ID 2.3) (WSRT p=0.464).

4.2.2. Comparison of the treatments

At the end of the second retrospective, the participants were asked to compare the treatments by using Questionnaire 2, see Table 8. Questionnaire 2 included statements about the retrospectives (first or second "session") which the participants were supposed to agree or disagree on a 7-point ordinal scale from "fully disagree"

Table 7
Summary of feedback from Questionnaire 1 (**bold** indicates the preferred technique)

Topic	Technique	N	Answers on Scale (%) *							Median
			1	2	3	4	5	6	7	
1. Collecting the causes (no variation in the method)										
1.1 Difficulty to detect problem causes	CED	51	-	7.8	15.7	9.8	29.4	33.3	3.9	5
	SL	50	-	10.0	10.0	16.0	36.0	22.0	6.0	5
1.2 Easiness to collect causes	CED	51	-	-	3.9	13.7	21.6	43.1	17.6	6
	SL	50	-	-	2.0	10.0	32.0	38.0	18.0	6
1.3 The method used to collect causes	CED	51	-	-	-	-	9.8	64.7	25.5	6
	SL	51	-	-	-	2.0	9.8	56.9	31.4	6
1.4 Usefulness of cause collection	CED	51	-	-	-	2.0	17.6	43.1	37.3	6
	SL	48	-	-	-	4.2	8.3	54.2	33.3	6
1.5 Importance of collecting sub causes	CED	51	-	-	-	5.9	17.6	45.1	31.4	6
	SL	50	-	-	-	2.0	16.0	62.0	20.0	6
2. Organizing the causes (variation in the method)										
2.1 The method used to organize causes	**CED**	51	-	-	2.0	2.0	19.6	58.8	17.6	6
	SL	51	-	-	2.0	9.8	45.1	31.4	11.8	5
2.2 Difficulty to get the big picture of problem causes	**CED**	51	5.9	17.6	27.5	17.6	19.6	9.8	2.0	3
	SL	50	6.0	14.0	18.0	12.0	30.0	14.0	6.0	4.5
2.3 Easiness to register problem causes	CED	49	-	4.1	8.2	22.4	38.8	22.4	4.1	5
	SL	50	2.0	6.0	12.0	20.0	20.0	32.0	8.0	5
3. Retrospective in general										
3.1 Cost-efficiency of the workshop	CED	50	-	-	2.0	4.0	24.0	36.0	34.0	6
	SL	49	-	-	4.1	4.1	30.6	34.7	26.5	6
3.2 Eff. in comparison to other methods	CED	39	-	-	-	10.3	12.8	38.5	38.5	6
	SL	38	-	-	-	5.3	18.4	36.8	39.5	6
3.3 Usefulness for corrective actions	CED	49	-	-	-	4.1	28.6	42.9	24.5	6
	SL	48	-	-	4.2	2.1	12.5	62.5	18.8	6
3.4 Usefulness of workshop in general	CED	51	-	-	-	2.0	9.8	39.2	49.0	6
	SL	48	-	-	2.1	4.2	12.5	41.7	39.6	6
3.5 This workshop was waste of time	CED	51	56.9	31.4	5.9	3.9	2.0	-	-	1
	SL	48	52.1	31.3	10.4	6.3	-	-	-	1
4. Social atmosphere (team dependent)										
4.1 Communication openness	CED	51	-	-	-	-	7.8	31.4	60.8	7
	SL	48	-	-	-	2.1	4.2	37.5	56.3	7
4.2 My team's effort	CED	50	-	-	-	-	2.0	56.0	42.0	6
	SL	49	-	-	-	2.0	10.2	57.1	30.6	6
4.3 My personal effort	CED	48	-	-	2.1	4.2	41.7	43.8	8.3	6
	SL	51	-	-	2.0	19.6	25.5	49.0	3.9	6
4.4 Team spirit	CED	51	-	-	-	5.9	23.5	35.3	35.3	6
	SL	48	-	4.2	-	8.3	4.2	52.1	31.3	6
4.5 Team members purposefully hided causes	CED	50	28.0	34.0	14.0	16.0	8.0	-	-	2
	SL	47	27.7	29.8	19.1	14.9	4.3	2.1	2.1	2
4.6 Team members did not dare to present all causes	CED	49	22.4	36.7	10.2	18.4	8.2	4.1	-	2
	SL	49	18.4	34.7	22.4	6.1	14.3	4.1	-	2

CED = Cause-effect diagram, SL = Structural list, N=number of respondents, * the scale was: 1=very low; 2, 3, 4=neutral, 5, 6, 7=very high

Table 8
Comparison of the treatments from Questionnaire 2 (**bold** indicates the preferred technique)

Statement	Second Session	N	Answers on Scale (%) *							Median
			1	2	3	4	5	6	7	
1. Registering the causes was easier in the first session	**CED**	21	4.8	28.6	23.8	23.8	4.8	14.3	-	3
	SL	30	3.3	13.3	13.3	16.7	16.7	20.0	16.7	5
2. Registering the causes was easier in this second session	**CED**	21	-	-	-	9.5	28.6	52.4	9.5	6
	SL	30	6.7	13.3	30.0	20.0	10.0	20.0	-	3.5
3. Organizing the causes was easier in the first session	**CED**	21	14.3	47.6	23.8	14.3	-	-	-	2
	SL	29	6.9	13.8	13.8	3.4	27.6	10.3	24.1	5
4. Organizing the causes was more difficult in this second session	**CED**	21	14.3	42.9	23.8	14.3	-	-	4.8	2
	SL	29	6.9	24.1	10.3	13.8	27.6	6.9	10.3	4
5. The number of causes created difficulties in the first session	**CED**	21	-	9.5	14.3	9.5	42.9	14.3	9.5	5
	SL	30	3.3	16.7	16.7	13.3	23.3	20.0	6.7	4.5
6. The number of causes created difficulties in the second session	**CED**	21	4.8	33.3	28.6	19.0	9.5	4.8	-	3
	SL	30	6.7	16.7	16.7	16.7	33.3	6.7	3.3	4
7. Outlining the causes was easier in this second session	**CED**	21	-	-	-	28.6	23.8	38.1	9.5	5
	SL	30	13.3	10.0	30.0	13.3	20.0	13.3	-	3
8. RCA should rather be conducted by using CED	**CED**	21	-	4.8	-	4.8	4.8	33.3	52.4	7
	SL	30	-	6.7	20.0	10.0	16.7	10.0	36.7	5

* The scale was: 1=fully disagree; 2=disagree, 3=somewhat disagree, 4=neutral; 5=somewhat agree, 6=agree, 7 = fully agree

to “fully agree”. We counted the answers of participants being present at both treatments (N=51). The questionnaire asked the participants to evaluate the easiness to register, organize, and outline the detected causes. The questionnaire also asked to agree or disagree whether or not RCA should be conducted by using CED instead of using the structural list. Table 8 summarizes the answers of the participants divided into those who used CED and the structural list (SL) in the second retrospective session. It seems that the retrospectives using CED were perceived as easier regarding *registering*, *organizing*, and *outlining* the detected causes. Additionally, most of the participants perceived that RCA should rather be conducted with CED than the structural list (a total of 75%). It is possible that this result is biased towards CED due to the somewhat loaded statement in Questionnaire 2.

4.2.3. Results from the group interviews

Table 9 summarizes the arguments that were acquired from the group interviews to describe the treatments. The concepts that we recognized indicated different pros and cons between the treatments. While the participants perceived that CED outperforms the structural list in its visual structure, they also perceived that the structural list (SL) outperforms CED in its readability.

From the interviews, we recognized three high level categories that linked the comments of participants together. These included *Sense making*, *Ease-of-Use*, and *Accuracy*. Sense making is about comments that describe how the treatments helped the participants to understand how the detected causes affect the problem together. Ease-of-Use is about comments that describe how the treatments helped the participants to use the cause and effect structuring technique. Accuracy includes comments that describe how the treatments helped the participants to detect causes.

The participants perceived that CED outperforms the structural list in Sense making and Accuracy. It was perceived that CED supports outlining the aggregations of causes (6 groups) and causal relationships (8 groups). Furthermore, the visual structure of CED was perceived as feasible for RCA (7 groups) and especially an easier

Table 9
Comparison of the arguments used for describing the cause and effect structuring techniques

Category	Concept	CED	SL
Sense Making	Supports outlining aggregation	*With CED it is easier to outline the aggregation of causes:* the number of comments (8) and groups (6).	*With the list it is easier to interpret the causes if the causes are not much interconnected:* the number of comments (1) and groups (1).
	Supports outlining causal relationships	*With CED it is easier to outline the causal relationships:* the number of comments (15) and groups (8).	-
	Supports thinking	*There is no list of causes in my brains, instead, there are causal relationships:* the number of comments (3) and groups (3).	*I consider these causes as a top-down list in my brains and thus the list is more feasible for me:* the number of comments (1) and groups (1).
	Supports discussion	*I think that CED improved discussion in the session:* the number of comments (2) and groups (1).	*While registering the causes less time is used to formalism, which improves the discussion:* the number of comments (2) and groups (1).
Ease-of-Use	Easier to use in general	*CED is easier to operate:* the number of comments (5) and groups (3).	*I experienced the list approach more lightweight than CED:* the number of comments (9) and groups (5).
	Easier to read	*CED is much easier to read than the list of causes:* the number of comments (2) and groups (1).	*The list approach results to more readable structure:* the number of comments (8) and groups (6).
	Easier to find registered causes	*It was relatively easy to find the causes already detected from CED whereas it was difficult from the list structure:* the number of comments (3) and groups (2).	*The list structure can visualize higher number of causes simultaneously helping to find causes already detected:* the number of comments (1) and groups (1).
	Easier to organize	*I think that less time is used to organize the causes with CED:* the number of comments (1) and groups (1).	*I assume that less time is used to organize the causes with the list:* the number of comments (1) and groups (1).
	Easier visual structure	*The structure of CED is much more feasible:* the number of comments (16) and groups (7).	-
	Easier to navigate	*CED is easier to navigate:* the number of comments (4) and groups (4).	-
Accuracy	Increases efficiency	*I assume that the graph structure helps to detect causes more efficiently:* the number of comments (6) and groups (4).	*The list approach requires less time while the causes are organized, which makes it more efficient:* the number of comments (2) and groups (2).
	Increases accuracy	*I think that with CED it is easier to focus on specific branches:* the number of comments (3) and groups (2).	-
	Increases systematics	*It was easier to contribute to CED as I was able to process the causes detected more systematically:* the number of comments (2) and groups (2).	-

technique to navigate the detected causes (4 groups). Additionally, the participants perceived that CED helped focusing on specific causes (2 groups) and it was easier to process the detected causes systematically (2 groups).

The participants also found the structural list as useful. It was reported that the structural list makes it easier to read the detected causes (6 groups). It was also claimed that the high readability makes the structural list lightweight and thus it increases the efficiency of the analysis (2 groups). However, CED was perceived as increasing efficiency more often (4 groups). The participants also claimed that the structural list is generally easier to use (5 groups). On the other hand, many participants reported the opposite (3 groups).

5. Discussion

In this section, we answer the research questions, compare our findings with prior works and outline possible threats to the validity.

5.1. RQ1: Is there a difference between the techniques in terms of the outcome of RCA?

This research question was studied with three sub questions. Below we summarize the answers. *RQ1a: Is there a difference in the number of the detected causes?* CED found more causes than structural list and the difference between the treatments has medium effect size (d=0.57). A total of nine teams out of eleven performed better with CED. However, the difference is not statistically significant due to small sample size. Thus, we interpret that our results give only weak evidence in favor of using CED in retrospectives.

RQ1b*: Is there a difference in the structures of the detected causes?* Our results in Section 4.1.2 showed that the number of causes increased between the first and third depth levels when using CED. Instead, for the structural list, the number of causes increased only among the first and second depth levels. The difference in the size of the third depth level is large and statistically significant. Therefore, we hypothesize that CED allows creating cause-effect networks that have more detected causes starting from the third level than ones created with structural list (a total of 75 vs. 60 detected causes on average), see Figure 7. Our interpretation of this is that CED encourages towards the deeper investigation of causes than the structural list, thus, using CED can be beneficial if a problem cannot be solved only by looking at the shallow causes.

The use of CED also increased the number of hub causes. As an average, 7% of the causes detected with CED explained more than one effect, whereas the proportion of such causes was only 3% when the structural list was used. The difference between the treatments is statistically significant and large. This suggests that CED enables the participants to link causes to each other more effectively. Thus, the knowledge created by CED is richer compared with the structural list that creates a more fragmented view for the participants.

RQ1c: Is there a difference in the characteristics of the detected causes? Our results in Section 4.1.3 showed that the treatments did not have a high impact on the characteristics of the causes, e.g. with both approaches the top cause was characterized as the output of management work. The shares of detected causes with similar characteristics correlated strongly between the treatments. This result provides strong evidence that the techniques used to organize and visualize the causes have no effect on the characteristics of the detected causes.

5.2. RQ2: Do the perceptions of retrospective participants vary between the techniques?

This research question was studied with two sub questions. RQ2a*: Is there a difference in the preferred technique?* The results from Questionnaire 1 indicate that the retrospective utilizing CED was perceived generally as a better technique to organize the detected causes. CED was evaluated as a "good" technique to organize the detected causes whereas the structural list was evaluated only as "somewhat good" (see Section 4.2.1). Similarly, the results from Questionnaire 2 indicate that the participants preferred using CED in the RCA of retrospectives. Furthermore, our results indicate that outlining the detected causes is easier with CED. Despite the difference between the treatments was not statistically significant (p=0.089), it was consolidated in the interviews and Questionnaire 2. In Questionnaire 2, CED was perceived as easier regarding registering, organizing, and outlining the detected causes. In the interviews, most of the teams reported that CED made it easier to outline the detected causes. To conclude our results, we assume that using CED in the RCA of retrospectives is reasonable as the retrospective participants prefer using it. However, also the structural list helps to organize the causes of problems. Additionally, it is not perceived significantly different than CED when the participants evaluate the outcome of RCA.

RQ2b*: How do the retrospective participants evaluate and describe the techniques?* Considering the similarities between the treatments, the results from the group interviews (see Table 9) indicated that the participants perceived both treatments as feasible for registering the causes. The results from Questionnaire 1 consolidate this assumption.

The participants agreed for both treatments similarly that it was easy to register the detected causes among the other causes. It is possible that this similarity was due to the fact that the facilitator was the one who registered the detected causes among the other causes based on the instructions of the participants (see Section 0). Furthermore, considering the differences between the treatments, the participants emphasized that CED outperforms the structural list when the detected causes are outlined. The visual structure of CED was described as feasible for RCA. It helped outline the aggregations of causes and made it easier to outline the perceived cause and effect relationships. The participants claimed that CED was easy to navigate and operate. Thus it was also easier to focus on the detected causes. Therefore, the participants perceived that CED increases the accuracy of the analysis and it improves sense making of the detected causes. There were arguments that support using the structural list, too. The participants claimed that the visual structure of the structural list allows more causes to be visible at the same time. The structural list was also described as easier to operate due to its high readability, as indicated by Ottensooser et al. (2012). Interestingly, it was claimed that the visual structure of the structural list is beneficial only if the number of detected causes remains low. Based on prior studies (McLeod and MacDonell 2011), software project problems are complex and they are often related to many causes.

To conclude, there is a difference between the techniques considering the perceptions of retrospective participants. In terms of organizing a high number of problem causes, the participants perceived that CED provided more flexible and visually attractive structure. Additionally, when making sense about the causes of problems, the participants perceived that CED helped to navigate the detected causes. Thus, the participants also experienced that the use of CED provided additional value for their software project retrospectives. Combining this conclusion with the actual outcome of the retrospectives means that CED is a better technique for RCA than the structural list. CED outperformed the structural list in the causal structures, its method effectiveness did not decrease, and it was also perceived as a better technique for RCA. Despite that it does not really matter if one method allows people to identify slightly more causes than the other, it truly matters whether the participants perceive the method as better. Thus, we recommend using CED instead of the structural list in the RCA of retrospectives.

5.3. Comparison to prior works

Lee et al. (1992) claimed that sharing cognitive maps, which include perceived cause and effect relationships between actions and their responses, result in organizational learning. The maps that they introduced follow the visual structure of CED. Our results support the recommendations of Lee et al. CED outperforms the structural list technique when the team is trying to learn from their problems. It helps in capturing the lessons learned from the teams and individuals more efficiently. This means that the individuals share their understanding about the causes of problems more efficiently. Thus, using CED helps individuals in sharing their knowledge on the causes of problems, which in turn is the key for organizational learning (Boh, Slaughter, and Espinosa 2007). This finding consolidates the prior studies recommending using CEDs in the RCA of retrospectives (Bjørnson, Wang, and Arisholm 2009; Lehtinen, Mäntylä, and Vanhanen 2011; Anbari, Carayannis, and Voetsch 2008; Dingsøyr 2005).

Considering alternative techniques to create CED (Bjørnson, Wang, and Arisholm 2009; Andersen and Fagerhaug 2006; Andersen and Fagerhaug 2006; Burnstein 2003; Stevenson 2005; Ishikawa 1990; Nakashima et al. 1999; Latino and Latino 2006; Rooney and Vanden Heuvel 2004; Ammerman 1998), it seems evitable that in software project retrospectives the diagramming technique should support network structures (Lehtinen, Mäntylä, and Vanhanen 2011). This is because of the hub causes (Bjørnson, Wang, and Arisholm 2009) (in our study their proportion was 7 % as an average). Duplicating the same cause many times increases the complexity of the visual structure as the number of cause statements increases. The fishbone diagram includes the same problem as the structural list, as it is a list structure (Lehtinen, Mäntylä, and Vanhanen 2011).

Furthermore, Björnsson et al. (2009) compared two CED techniques with a controlled student experiment and showed that using the fishbone diagram (CED) in RCA resulted in a decreasing number of new problem causes detected when compared with the directed graph (CED). Our study resulted in a similar finding about the structural list, but the difference in the number of detected causes was not as big as was reported by Björnsson et al. (Bjørnson, Wang, and Arisholm 2009). One explanation for this difference could be the RCA facilitator of the retrospectives. Björnsson et al. (Bjørnson, Wang, and Arisholm 2009) assumed that the difference between the treatments might have been less if they would have used professional facilitators. Another explanation could be the method used to collect and register the causes. The method that we used did not change between the treatments. Instead, the prior experiment used *"a nominal brainstorming technique"* with the directed graph and *"an interactive technique"* with the fishbone diagram (Bjørnson, Wang, and Arisholm 2009). Furthermore, in contrast to the structural list technique, the fishbone diagram steers the participants to classify the detected causes during recording (Lehtinen, Mäntylä, and Vanhanen 2011). Thus, it is possible that the cause classification decreases the number of detected causes

significantly. If the participants are forced to consider the cause classes simultaneously while trying to detect new causes, less new causes are detected because the participants need to focus on two things simultaneously.

Our research problem was following: Is CED really needed in the RCA of software project retrospectives, and if so, why? A network structured CED is likely needed in the RCA of software project retrospectives, because it helps the retrospective participant in explaining and making sense about the perceived relationships of the causes of problems. Our results indicate that CED improves the RCA of retrospectives in comparison to using the structural list. It is visually more attractive and technically more effective than the structural list. Additionally, the retrospective participants prefer using CED. These hypotheses are in line with the prior studies which have recommended using CEDs in the RCA of software project retrospectives (Bjørnson, Wang, and Arisholm 2009; Lehtinen, Mäntylä, and Vanhanen 2011; Anbari, Carayannis, and Voetsch 2008; Dingsøyr 2005). Furthermore, our results indicate that the direct graph improves sense making and accuracy of RCA. This hypothesis is in line with the prior study about the cognitive maps (Lee, Courtney, and O'Keefe 1992).

5.4. Evaluation of the research

This section discusses the validity of our results using a validation scheme presented by Runeson and Höst (2008). We will present the construct validity in Section 5.4.1, the internal validity in Section 5.4.2, the external validity in Section 5.4.3, and the reliability of the study in Section 5.4.4.

5.4.1. Construct validity

Construct validity reflects the extent to which the studied operational measures really represent what is investigated according to the research questions (Runeson and Höst 2008). In this study, the operational measures included the outcome of RCA, questionnaires, and interviews.

In order to analyze the characteristics of detected causes, we used a classification system (see Section 3.4.2). Classifying the causes likely dissipated their dissimilarities and simultaneously highlighted their similarities. This means that there is a risk for the construct validity that the detected causes were not as similar as our results indicated (see Section 4.1.3). Previously, we have qualitatively analyzed the causes which were detected in this study (Vanhanen, Lehtinen, and Lassenius 2012) and we did not note any differences in the detected causes between the treatments. Additionally, during this study, we did not note any differences in the detected causes while using the classification system. Furthermore, there are no good reasons to assume that the detected causes are significantly different when they are detected with CED versus the structural list.

Considering the evaluations of participants, there is a risk for construct validity regarding the questionnaires. It is possible that the participants understood the questions in the forms differently, and thus their evaluations varied. The items in Questionnaire 2 were somewhat loaded and fuzzy. It is also possible that some participants were more or less critical than others while making the evaluations. Furthermore, it is possible that the participants did not evaluate the treatments objectively. A total of 61 participants filled in the questionnaires. Additionally, 84% of the participants were present at both retrospectives. We believe that there were enough participants to make a statistical comparison between their evaluations. Table 7 summarized the feedback from Questionnaire 1. The standard deviation between the evaluations was small. Additionally, the participants evaluated similar parts of the treatments similarly and different parts somewhat differently. Thus, it is likely that the participants understood the questions at least somewhat similarly and most of them were objective. Additionally, this means that the questionnaire worked as planned. Furthermore, we used the Wilcoxon Signed Rank Test with alpha level 0.05 to detect systematic differences in the evaluations of an individual respondent. The alpha level was also corrected by using the Bonferroni correction resulting in a required level of statistical significance ($p = 0.0026$). Thus, even if the participants were more or less critical while making the evaluations, we were able to recognize the preferred treatment.

Considering the arguments used to describe the treatments, there is a risk for construct validity regarding the group interviews. It happened that some team members did not state any comments as the other team members dominated the interview. Thus, it is possible that the results from interviews are skewed to the opinions of dominating participants. However, most of the participants from each team provided comments about the treatments. Thus, in order to draw out conclusions and make hypotheses about the treatments, we believe that our results represent the perceptions of participants inclusively enough.

Furthermore, the first author transcribed the interviews and used open-coding to draw out the conclusions. Thus, there is a risk for construct validity regarding the possible misinterpretations of the interviews. However, the qualitative research method that was used (see Section 3.4.4) utilizes the comments and key words the retrospective participants used while they did the comparison between the treatments. Thus, the conclusions made by the first

author are based on the comparisons the retrospective participants made. Additionally, the interviews were conducted for each group separately. Thus, the conclusions are based on many data sources instead of few. The interviews were also video recorded. Thus, while transcribing the interviews, the first author was able to recall the social atmosphere and specific comments about the treatments.

5.4.2. Internal validity

Internal validity is of concern when the causal relations of the measured factors are examined (Runeson and Höst 2008). In this study, the examination covered the causal relationships between the treatments and response variables.

The research settings of each team were similar in both retrospectives because we controlled the roles of participants, used language, physical conditions, the retrospective facilitator, the education background, cultural differences, skills, and differences in ages and sex. We can see from Table 7 that the retrospective participants evaluated the openness in communication, personal effort, team effort, and team spirit similarly in both treatments. They also evaluated that their team members did not significantly hide causes during the retrospectives and they dare to present the detected causes for other team members. Thus, we assume that also the motivation and team spirit remained similar between the treatments. We also controlled the retrospective method. It was conducted similarly in all retrospectives and the similar parts of the method were also evaluated similarly (see Table 7). The only significant difference in the evaluations was related to the variation in the treatments.

Considering the comparison of the number of detected causes and causal structures, there is a risk for internal validity regarding the specific focus of each retrospective. The specific focus of the retrospectives varied (see Table 5), because the team members voted slightly different problems to be further analyzed with RCA (see Section 0). Thus, there is a risk for internal validity regarding our comparison results on the number of detected causes and causal structures. Considering this risk, most of the teams (seven out of eleven) had a highly similar focus in both of their retrospectives as the voted problems were similar in both retrospectives. Thus, the risk was low in most of the teams. Furthermore, the results from these teams are in line with the results of all teams together. Additionally, the detected causes remained similar in each team (see Section 4.1.3). Thus, even though the voted problems slightly varied, similar causes were recognized in the retrospectives. Therefore, we believe that the voted problems did not make a major bias to the comparison results.

There is a risk for internal validity regarding the number of retrospective participants (see Table 5). In six teams, the number of participants varied +/-1 between the retrospectives. Thus, it was possible that the variation in the number of participants biased the comparison results. We evaluated this risk by calculating the correlation between the number of participants and the number of detected causes. The null hypothesis was that the number of participants in the teams does not correlate with the number of detected causes. We tested both treatments (A & B) separately and together (AB). None of these tests resulted in a significant correlation (Pearson's $pA=0.658$, $pB=0.727$, $pAB=0.566$) and the coefficient values were very low ($rA=-0.151$, $rB=-0.119$, $rAB=-0.129$). Thus, the tests did not reject the null hypothesis. Additionally, the difference between the numbers of participants in treatments was not statistically significant over the teams (Wilcoxon Signed Rank test gives $p=1.000$). Thus, the potential bias in our comparison results caused by the varying number of participants cannot be concluded with these tests.

Furthermore, our results were neither highly dependent on the order of the treatments. For the project teams which started with the structural list, the average number of detected causes was 100 in the first retrospective. When those teams used CED in their second retrospective, the average number was 111, 11% increase as an average. For the project teams which started with CED, the average number of causes was 103. Instead, when those teams used the structural list in the second retrospective, the average number was 89, 14% decrease as an average. Additionally, the project teams which detected a high number of causes with structural list also did that with CED and vice versa. Pearson's correlation between the treatments of each team based on the number of causes is strong ($r=0.580$, $p=0.061$) but it is not statistically significant due to the low number of teams ($N=11$). Furthermore, the correlation between the treatments of each team on the average number of causes per participants is strong and it is also statistically significant ($r=0.648$, $p=0.031$). Furthermore, as the change in the number of causes between the treatments was very similar in each team, we conclude that the order of treatments did not violate the comparison results. This also indicates that the risk of learning effect bias in the comparison results is low.

5.4.3. External validity

External validity is concerned with whether it is possible to generalize the findings of the study and to what extent they can be generalized (Runeson and Höst 2008). Considering the method effectiveness, causal structures, and the perceptions of participants, our results indicate that CED outperforms the structural list in the RCA of retrospectives which are conducted in small software project teams with a skilled facilitator. We believe that the

external validity of this conclusion is high. However, our results are based on the retrospectives of student teams. Thus, there is a risk for external validity regarding the retrospectives which are conducted in industrial software teams. Our results cannot be used to present the absolute level of improvements, but we believe they are valid for representing the improvement trend over the treatments (Runeson 2003). Our results are also limited to retrospectives where only negative project experiences are analyzed, whereas the prior study considered also positive experiences (Bjørnson, Wang, and Arisholm 2009). Furthermore, our results are limited to RCA which is conducted by using a monitor and software tool. Thus, we cannot generalize our findings to RCA which is conducted by using a whiteboard and Post-it notes.

In industrial software teams, the number of causes could easily be over a hundred (Lehtinen, Mäntylä, and Vanhanen 2011). Our results show that CED improves the effectiveness of retrospectives when a high number of causes are detected. We conducted somewhat similar retrospectives to CED in four software companies covering the work of over 100 employees in each company (Lehtinen, Mäntylä, and Vanhanen 2011). As a result, the lowest number of detected causes was 163, which is significantly more than the number of detected causes in the project teams of this study (see Table 5). Thus, we believe that using CED in these four companies was a more optimal choice than the structural list. Respectively, our recent study with industrial software teams has consolidated this assumption by indicating that the motivation of the teams to conduct retrospectives increase while CED is used instead of writing down simple memos about the problems and their causes (Lehtinen et al. 2014b).

Furthermore, despite our conclusions are based on the retrospectives of small software teams, we believe that our results are also valid in large software teams. We assume that the complexity and cross-functionality of the problems of larger software project teams would increase the number of detected causes. If few causes of the problem are detected, then it is likely that the visualization technique does not make much difference to the retrospective outcome. However, when a high number of causes are detected, then the need to use CED increases.

Considering the perceptions of retrospective participants, we believe that the external validity of our results is also high. A similar conclusion about the RCA method which utilizes CED has been presented (Bjørnson, Wang, and Arisholm 2009; Lehtinen, Mäntylä, and Vanhanen 2011; Lehtinen et al. 2014b). It has also been claimed that the flexible structure of CED is one of its advantages (Bjørnson, Wang, and Arisholm 2009). Additionally, our results are not limited to perceptions of a few individual. Instead, our results cover the opinions of dozens of people.

5.4.4. Reliability

Reliability is concerned with the extent to which the data and analysis are dependent on a specific researcher (Runeson and Höst 2008). Our results are based on quantitative and qualitative data. Considering the quantitative data, there is a risk for reliability as the first author steered the retrospectives. Even though he tried to act as objectively as possible, it is possible that he unconsciously biased the results somehow. We tried to minimize such bias. Each retrospective strictly followed the retrospective method introduced in Section 0. Respectively, the first author is familiar with RCA and the software tools used in the treatments and thus he did not need to use time to learn to use them properly. We assume that using the same facilitator in each retrospective was an advantage as now the retrospectives are more comparable than they would have been if the facilitators would have changed over the teams or treatments.

Furthermore, there is a risk for reliability regarding the evaluations of participants. It is possible that the personal characteristics of the facilitator affected the evaluations. To control this problem we used the paired design and randomized the starting order of treatments for each team. Additionally, the participants did not know our research goals in advance, and similar questions were asked in questionnaires after both treatments. Therefore, we were able to analyze how the answers of individual respondents varied over the treatments. Additionally, we underlined for the participants that they should evaluate the treatments as objectively as possible. Furthermore, we used the group interviews to consolidate the results from questionnaires. The results from both data sources are in line with one another.

6. Conclusions and future work

CED is a commonly recommended technique for RCA, as indicated in our earlier literature review (Lehtinen, Mäntylä, and Vanhanen 2011). However, there are no studies where the effectiveness of using CED is compared with the effectiveness of RCA without it. In this paper, we performed a controlled experiment comparing CED with the structural list with project teams (n=22) of a software engineering capstone course. We evaluated the outcome of RCA in software project retrospectives and the perceptions of retrospective participants using CED in comparison to those using the structural list technique. We made three main findings in this research.

First, we found weak evidence that the measured output of CED is better in comparison to the structural list. CED increased the method effectiveness with medium effect size (d=0.57), however, the difference is not statistically significant (p=0.065) due to small sample size (n=22). This difference was caused by the fact that CED had more causes on the deeper levels than simple memos. Thus, using CED can be beneficial if a problem cannot be solved only by looking at the shallow causes. Finally, the cause network of CED had more hub causes indicating the CED allows the creation of richer understanding about the problem.

Second, in terms of the perceptions of the retrospective participants, there are significant differences between the techniques. CED was perceived as a better technique in the surveys and most of the participants (75%) prefer using CED, instead of the structural list.

Third, the qualitative analysis of both methods showed that both methods had advantages. CED was perceived as a better technique to organize the causes of problems, because it provides a more flexible and visually attractive structure and it is also perceived as easier to navigate when making sense about the causes of the problems. The structural list was seen as easier to read and it could present more causes simultaneously on screen than CED.

Our results indicate that using CED in the RCA of retrospectives could be beneficial because it was preferred by project team participants; it also provides richer analysis on the interrelations of causes and it is at least as efficient as the structural list. However, the differences between these techniques are not massive.

Obviously, software companies rarely have time to conduct retrospectives (Glass 2002). However, they are likely valuable and therefore they should also be as optimized and lightweight as possible. In the future, more comparisons between the CED techniques should be done. We should continue the work of Björnsson et al. (2009) as one of the major challenges in the RCA of retrospectives is the high number of causes of problems. Similarly, we should continue to develop new emerging methods for capturing and refining the findings of software project retrospectives in order to improve the organizational learning. We should also analyze the feasibility of software tools in the RCA of retrospectives. For example, software tools that support conducting RCA in distributed retrospectives are scarce (Lehtinen et al. 2014b).

Appendix 1: Questions asked on Questionnaire 1

This inquiry is 100% anonymous. The people names won't be published. All the results are analyzed as a one mass of answers.

1. Your name: […]

Answer by circling a choice for each question.

My role in the project team is… [1=project manager, 2=quality manager, 3=architect, 4=developer]

2. Cause Collection

The scale was: [1=very bad; 2=bad, 3=somewhat bad, 4=neutral; 5=somewhat good, 6=good, 7 = very good, *=I don't answer]

- Technique used to collect the causes is… [Result ID = 1.3]
- Technique used to organize the causes is… [Result ID = 2.1]
- Advantageousness of cause collection in comparison to used effort was… [Result ID = 3.1]
- Correctness of the detected causes is…
- Easiness to solve the detected causes is…
- My effort in the cause collection was… [Result ID = 4.3]
- Effort of my team in the cause collection was… [Result ID = 4.2]
- Efficiency of the method to detect improvement targets compared to the other methods you have experience… [Result ID = 3.2]

3. General

The scale was: [1=fully disagree; 2=disagree, 3=somewhat disagree, 4=neutral; 5=somewhat agree, 6=agree, 7 = fully agree, *=I don't answer]

- There was an open communication in the session… [Result ID = 4.1]
- In general, this was a useful workshop… [Result ID = 3.4]
- The used RCA method helps to develop corrective actions… [Result ID = 3.3]
- Team spirit of our project team is great… [Result ID = 4.4]
- This workshop was nothing more than waste of time… [Result ID = 3.5]

4. General

The scale was: [1=fully disagree; 2=disagree, 3=somewhat disagree, 4=neutral; 5=somewhat agree, 6=agree, 7 = fully agree, *=I don't answer]

- Detecting the fundamental causes of the problem was challenging… [Result ID = 1.1]
- Problem causes should be collected by writing them on papers…
- Problem causes should be collected by discussing on them…
- It is a good idea to articulate publicly the written causes…
- The participants purposefully did not name some important causes… [Result ID = 4.5]
- The participants did not care to name all the causes publicly… [Result ID = 4.6]
- The only way to solve a problem is through solving its fundamental causes…
- It was hard to me to get the big picture of the fundamental causes of the problem, because of their high number… [Result ID = 2.2]
- It was easy to register the causes I detected among the other causes… [Result ID = 2.3]
- It is important to collect sub causes of a problem… [Result ID = 1.5]
- Technique used to collect problem causes is easy to use… [Result ID = 1.2]
- Technique used to collect problem causes is useful… [Result ID = 1.4]

Appendix 2: Questions asked on Questionnaire 2

This inquiry is 100% anonymous. The people names won't be published. All the results are analyzed as a one mass of answers.

1. **Your name:** […]

Answer by circling a choice for each question.

The scale was: [1=fully disagree; 2=disagree, 3=somewhat disagree, 4=neutral; 5=somewhat agree, 6=agree, 7 = fully agree, *=I don't answer]

- I think that RCA should rather be conducted by using the directed graph than by using the structural list…
- The high number of causes in the first workshop created a problem of being difficult to get the big picture of the fundamental problem causes…
- It was easier in the first workshop to register the causes I detected among the other causes…
- Technique used to collect the causes in the first workshop is easier than the method used in this second workshop…
- Technique used to organize the causes in the first workshop is easier than the method used in this second workshop…
- The high number of causes in this second workshop created a problem of being difficult to get the big picture of the fundamental problem causes…
- It was easier in this second workshop to register the causes I detected among the other causes…
- It was easier to get the big picture of the fundamental causes of the problem in this second workshop than in the first workshop…
- Technique used to organize the causes in this second workshop is more difficult than the method used in the first workshop…
- Technique used to organize the causes in the first workshop is more difficult than the method used in this second workshop…

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