PROTOTYPING A CONTINUOUS IMPROVEMENT AND INNOVATION PROGRAM

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ABSTRACT

This paper investigates a development process of prototype a continuous improvement and innovation (CII) program that improves Engineer-To-Order (ETO) processes. Research for this paper comprises an in-depth description of development of a CII-program in a probe-and-learn process. The study applies action research in collaboration with a Small- and Medium-sized Enterprise (SME), applying prototypes of a CII-program on cross-functional challenges in ETO processes. Findings from the development process show that practitioners gain increased insight into cross-functional ETO-processes and the improvement process.

INTRODUCTION

Manufacturing enterprises delivering ETO solutions gain a competitive advantage from short lead-times (Willner et al. 2016) and look for ways to innovate effectively (Çakar & Ertürk 2010). Engineering lead-times include developing or adapting specifications to customer's needs within order fulfilment time (Willner et al. 2016). In practice, engineering designers set the pace for the subsequent functions, as machining cannot start before the drawings are ready. Assembly may start before all parts are finished and delivered if the received parts fit in the order of assembly, such as when having parts for the frame of the equipment or parts for a sub-assembly.

Scholars suggests that increased standardization and automation of design tasks can reduce lead-time in ETO processes (Willner et al. 2016). However, ETO manufacturers struggle in finding the appropriate degree of standardization and automation (Willner et al. 2016). Scholars claim to have solutions to this challenge by applying strategies regarding configuration of design and computer-aided-design (Willner et al. 2016). Consequently, top management in manufacturing enterprises must balance contradictory goals (S. Adler et al. 2009).

Other scholars suggest that continuous improvement of products and processes can deliver incremental innovation and increase participation (Bessant & Caffyn 1997). Boer and Gertsen (2003) define the concept of continuous innovation as "… the ongoing process of operating and improving existing, and developing and putting into use new configurations of products, market approaches, processes, technologies and competencies, organisation and management systems." However, it remains a central task for practitioners and scholars to understand which organizational practices can be adopted to balance and maintain short-term efficiency and long-term innovation capabilities (Martini et al. 2013).

Continuous improvement and innovation of products emphasize that testing prototypes in early stages of the product development process allows learning from errors through experimentation (Cole 2002). Now consider a Continuous Improvement and Innovation (CII) program for a product, and a SME the user applying a prototype of the CII-program. Similar to prototypes of products, the expectations would then be that applying prototypes of a CII-program generate insights about ETO processes for practitioners as well as learnings about the CII-program for the program designer (in this case the author). In the following, this paper seeks to understand what practitioners and researchers can learn from prototyping a CII-program in a probe-and-learn process. Even though the CII-program itself is a contribution to practitioners and scholars, it will not be discussed in this paper.

The remainder of this paper presents literature on prototyping as a probe-and-learn process and other continuous improvement and innovation programs. The second section presents the applied action research method and case description. The third section evaluates data and methods applied in this study. The fourth section then presents results of the study and include design criteria, prototypes of the CII-program and the final program. The fifth section discuss the insights practitioners gained from the study. Finally, the conclusion directs attention to further research agendas.

LITERATURE AND THEORY

PROTOTYPING

Prototyping is a familiar practice in conventional product development, as is beta testing within software development (Cole 2002). Product development applies prototypes to initiate a dialogue with production about manufacturability and marketing to customers' needs (Cole 2002). Designers prototype product concepts, engineers prototype production designs, and software developers prototype programs—all in order to gain feedback from customers or other stakeholders at an early stage of development (Ulrich & Eppinger 2012). Testing prototypes with users then becomes an iterative and learning process for both designers and users (Ulrich & Eppinger 2012).

Cole (2002) proposed a probe-and-learn process for product development that comprises probe, test, evaluate, and learn (refine) as a way of speeding up Deming's Plan, Do, Check, Act (PDCA) model. The purpose of the probe-and-learn process is to receive instant feedback from users in product development (Cole 2002). Probe-and-learn is a way of approximating the product design (Cole 2002).

CONTINUOUS IMPROVEMENT AND INNOVATION

The purpose of the CII-program is to support manufacturing enterprises that intend to enhance their ability to innovate effectively. The program builds on assumptions in organizational learning suggesting that organizations learn from experience and experimentation, from solving their own problems, and that solving these problems develop the organizational design (Argyris & Schon 1996).

There are a few examples in literature that propose combining continuous improvement and innovation in a program.

Buckler (1996) proposed an individual learning process for continuous improvement and innovation. The learning process comprises ignorance, awareness, understanding, commitment, enactment, and reflection as elements (Buckler 1996). The premise for the program is leadership's attempt to enable a learning system supporting individuals' learning (Buckler 1996). As an important feature of his model, Buckler (1996) emphasize a progressive process where participants reflects on questions: "What have we learned?" and "How have we learned?"

CIMA (Euro-Australian co-operation centre for continuous Improvement and innovation Management) proposes a methodology that maps the current level of learning and knowledge management (strengths and weaknesses) as a basis for intra-firm and inter-firm comparison (Boer et al. 2001). Furthermore, Boer et al. (2001) provide guidelines for improving learning and knowledge generation processes in product innovation. The CIMA operationalized the model in questionnaires and developed a knowledge base comprising data from more than 80 companies (Boer et al. 2001).

So far, the author has found no examples in literature applying prototyping or probe-and-learn processes for developing and integrating continuous improvement and innovation programs into ETO processes.

DATA AND METHODS

This study applied action research enabling a mutual learning process and a collaborative partnership between a scholar and a company (Bradbury & Reason 2003). Action research provides the company with self-help capabilities while the scholar gains access to real-life data (Coghlan & Brannick 2014).

The author designed the CII-program through four action research cycles, each comprising four steps: developing a construct, planning action, taking action, and evaluating action. Figure 1 illustrates an action research cycle. Subsequently, the author revised the CII-program and planned the next step (Coughlan & Coghlan 2002; Coghlan & Brannick 2014). The action research process was therefore applicable for a probe-and-learn development process for a CII-program.

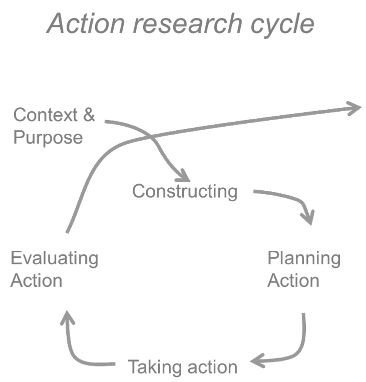

Figure 1. Action research cycle of constructing, planning action, taking action, and evaluating action (Coughlan & Coghlan 2002; Coghlan & Brannick 2014).

RESEARCH DESIGN

A pre-step of understanding the context and purpose of the study was formed before executing cycles of constructing the issue, planning action, taking action, and evaluating action (Coghlan & Brannick 2014). Each action research cycle had a specific focus:

The 1st cycle aimed to scope the project together with the management team in the company to develop a mutual understanding of the company's challenges related to innovating effectively and for management to select a focus for applying the program.

The plan was to conduct semi-structured interviews with key informants, visit workplaces, and participate in meetings to gain insights into what challenges the organizational members were discussing and trying to solve as part of their daily work. Transcriptions of interviews and observations would then be analyzed and the findings presented to the company's management team. Figure 2 illustrates the first action research cycle.

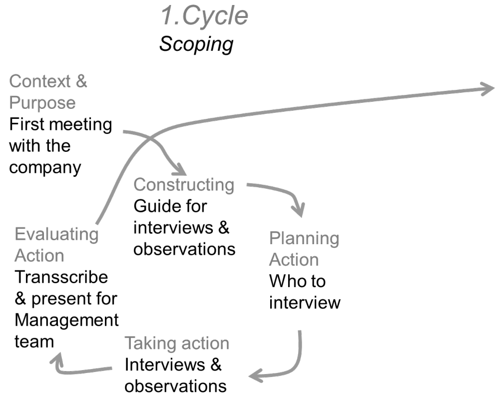

Figure 2. The first action research cycle included a first meeting with the company to prepare our collaboration, construct guides for interviews and observations, plan interviews, complete interviews and observations, transcribe interviews, and present preliminary findings to the management team.

The author completed four semi-structured interviews with the CEO, finance director, production manager, and engineering manager. The managers were asked about challenges in the company and their department. In addition, the author observed internal project meetings, shop floors, and engineering offices. Preliminary findings about the company's challenges were presented to the management team, who then defined the focus for applying the program in the following cycle.

The 2nd and 3rd cycle comprised interventions where prototypes of the CII-program were applied to problems the company found relevant. Design principles directed the author's development of the first prototype of the CII-program. The CII-program was refined between the two applications of the prototype.

The plan was to facilitate a series of interventions in each research cycle where the author facilitated the interventions in a group of organizational members working on a specific ETO project. These interventions were expected to solve specific problems in ETO processes and deliver data about the learning process in the CII-program. Figure 3 illustrates the process in the 2nd and 3rd cycle.

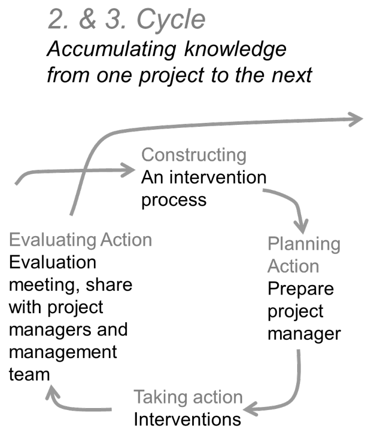

Figure 3. With input from the first action research cycle, the following two action research cycles applied prototypes of the CII-program in constructing an intervention process (the program), preparing the responsible project manager, applying the program in interventions, evaluating the activities with the project team, and sharing findings with other project managers and the management team.

In the first application of the CII-program (and 2nd cycle), a project team working on recurrent projects for a specific customer aimed to accumulating knowledge from one project to the next. The project team consisted of a project manager and three designers. The second application of the CII-program (and 3rd cycle) aimed to improve product quality as part of their daily work focused on developing an ETO process within a major project for a customer. The activities involved a project manager, a Lean manager, and employees from the assembly department. For both the 2nd and 3rd cycles, the study evaluated the activities with the participants, shared experiences with other project managers, and presented gained insights to the management team.

The 4th cycle comprised a test of a revised version of the CII-program, in which organizational members across functions solved problems related to ETO processes by following the steps in the program.

The plan was to test the CII-program by applying it to another ETO process emphasizing steps for developing and implementing solutions to problems identified in the first part of the study. Activities in the test were different from the first applications of the CII-program due to a revision of design criteria and program activities. Figure 4 illustrates the process in the 4th cycle.

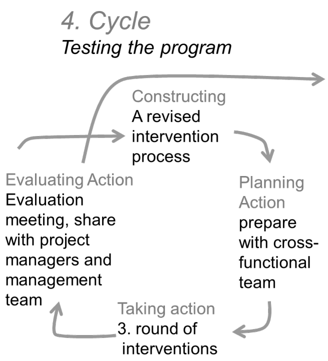

Figure 4. The fourth action research cycle tested the CII-program based on input from the previous cycles. The process included revising activities in the intervention process (CII-program), preparing activities with a cross-functional team, completing the test, evaluating the activities with the participants, and sharing findings with other project managers and the management team.

The final test of the CII-program involved a cross-functional group representing quality, production, logistics, and engineering functions. This cross-functional group prepared and planned the activities, elaborated on the design criteria defined by the management team, generated ideas, and developed prototypes of these ideas. The cross-functional group then presented selected solutions to a representative from the management team (production manager).

Activities in the four action research cycles generated data for this study, including transcribed interviews, observations, intervention dairies written by the author, and field data such as notes, pictures, and information collected about the organizational design. Two qualitative analyses of the collected data focused on challenges in a SME and an organizational learning perspective regarding the CII-program. The first analysis included inductive coding of data from the first action research cycle. The second analysis included a template analysis of data from the 2nd, 3rd, and 4th cycles using the 4I framework (Crossan et al. 1999; Zietsma et al. 2002). Analysis of the CII-program is not included in this paper.

THE CASE

A SME serves as a typical case illustrating the development process of a CII-program. The participating SME designs and manufactures customized equipment for the graphics industry. The company changed its strategic focus from single stand-alone projects to small, customized series of projects, where engineering increasingly reuses designs from previous customer projects. Management's objective is to sustain the SME's flexibility in delivering customized solutions while increasing the rate of standardization to improve efficiency. The application of the CII-program focused on sharing knowledge across functions in ETO processes. ETO processes involve organizational members of various functions such as sales, production, and naturally engineering. Recurring quality problems and delays in ETO processes could hurt the customer experience of products and thereby compromise the company's competitiveness. ETO processes have a short lead-time relative to new product development. In rapidly repeated ETO processes, it was possible to use the findings from one action research cycle in the next. Furthermore, the simple and organic organizational structure in a SME made the context relatively predictable and therefore favorable for applying prototypes of an incomplete CII-program.

In the first action research cycle, preliminary findings revealed conflicting interests and processes of trying to align these interests. The study identified three main challenges: First, four business units within the SME generated different needs in the business processes. Second, the board's expectations of a stable turnover combined with a short sight for new orders and volatile order income challenged resource management in engineering and production. Third, specialized knowledge about the customized equipment was stored as documentation in the projects and individually by engineers, thus limiting knowledge sharing. The management team chose the third topic as focus for the first series of interventions.

In the second action research cycle, the project manager's purpose for applying the program was to improve knowledge sharing within the project team in order to work more efficiently and use less hours for the design work. The project team designed equipment for a customer with several plants around the world. The project team worked on the eighth and ninth piece of equipment consecutively. Designers customized each piece of equipment for a specific factory. According to the project manager, 80% of the design work was "copy-pasted" from previous projects that had exceeded budgeted costs. The author prepared the project manager and facilitated the interventions. The interventions resulted in a board created to share knowledge on current projects. The project group evaluated the interventions at a one-hour workshop, where they summed up the interventions and handed over ideas for further improvements to a Lean manager. The project manager for the next application of the CII-program participated in the evaluation workshop. Additionally, the project manager and a member of the project group performed a self-assessment of the process. At the time of evaluation, two of the four members of the project group had left the company. The project manager presented findings at a regular meeting for other project managers. A one-hour standing meeting gave the management team a report back on findings. Findings from the second cycle provided the management team with information scoping the third cycle.

The third action research cycle focused on developing an ETO process within a major project for a customer. The project manager aimed to reduce recurring deviations in equipment design. Deviations are errors such as missing holes in parts that designers must correct in the documentation of the equipment.

Participants highlighted two types of main issues in preventing reoccurring deviations. First, they questioned whether assembly actually registered all deviations rather than only correcting the errors, they found. It became obvious that not all technicians found it worth the trouble to file a registration in the IT-system, for in their experience, designers did not correct the deviations anyway. This latter complaint was the second issue, and participants tested both issues in the specific project. The test showed that assembly had registered the expected amount of deviations and that designers had taken action on registered deviations. However, when trying to test how many of the deviations reoccurred in the following project a few months later, the assembly leader found that another assembly leader had not registered deviations in the beginning of the project. Therefore, comparisons of the deviations in the two projects were impossible. Consequently, the management team raised an issue about divergence of role and responsibilities. Furthermore, overlapping projects caused delays in corrections when drawings for a project were reused (copied) before the first project was finished in assembly. The findings also confronted management team with a third issue about the importance of apparently insignificant deviations. Looking through deviations of the project revealed that 42% of the deviations regarded holes (e.g., placed wrong, missing, wrong diameter, missing thread).

In the fourth action research cycle, the management team scoped the task and formed a new cross-functional group to participate in testing the program. Scoping the task comprised of setting objectives and design criteria for solutions. The goal set by the management team was to achieve a shorter delivery time, fewer repetitive errors, and an improved ability to formulate brilliant ideas. The management team also set some guidelines regarding design criteria. The management team chose that the group should apply rapid prototyping, where some prototypes of the solutions constructed with "cardboard and paper" were tested.

The four participants in the group represented production, logistics, engineering, and quality functions with the quality manager as appointed leader of the group and the author as facilitator. The main activities included brainstorming solutions, creating a number of prototypes, testing the prototypes, and selecting 1-2 solutions based on the design criteria. The group focused on the deviation system and measuring its effects on two specific ETO processes. The group had 34 suggestions and chose to specify two prior to a presentation to management represented by the production manager.

EVALUATION OF DATA

During the study, it was of outmost importance to the author to base relationships with participants on mutual trust. The author spend considerable hours and days over two and a half year allowing the author and the researched organization to become closely acquainted. Organizational members on mutual levels and across functions contributed to the CII-program design by taking part in and evaluating activities in the CII-program. The management team contributed by choosing a focus and in the test by selecting design criteria and methods. Participants in the interventions influenced program design through suggestions of tools and methods and by evaluating the activities in each action research cycle. Throughout the development process, the author used the metaphor “prototype” for the CII-program, making it apparent to participants that the CII-program was not finished work.

In this study, the author took the role of facilitator of interventions and researcher. As such, the author was both a researcher exploring the applicability of prototyping in developing a CII-program and a designer developing and testing a CII-program. Scholars can question whether research for this study truly is action research as the author developed the program at the home desk before applying prototypes.

The author’s ontological and epistemological assumptions were central to the choices made in this study. In this study, the author adopted a subjective perspective and understood the concept of learning as processes that continuously evolve based on individual and collective experiences. The subjective stance also included the author’s perception of organizations as collections of physical and social entities that also include social relations and processes. The author therefore humbly ask scholars to evaluate data in this study from this subjective stance.

RESULTS

The following section first presents the design criteria for developing the program, then the prototypes of the program applied in the case, and the final version of the program applied in the test.

DESIGN CRITERIA

Initially, the intention was to use a capability development approach where activities were limited in time and had a specific task and objective (Argyris & Schon 1996). Management should assign a specific task to a small group of participants. This group should involve “strangers” such as organizational members outside their own function (March 1991). The result or outcome of the activities, such as countermeasures to a problem, would be contained or coded into a work standard and the effect measured and monitored. The program should pay attention to the learning process in the management team, the organizational structure, mutual protection and trust, designate roles to the participants, and have management define the task and hand it over to a small group. In addition, the initial program emphasized framing and re-framing as core learning activities that could encourage explorative behaviors.

The design criteria were revised after applying prototypes of the CII-program twice. Eight design criteria directed the development of the final program. Criteria 1 to 4 concerned management scoping a task and setting the contextual stage for applying the CII-program (what, who, why, and when) (Argyris & Schon 1996). Criteria 1 proposed a task-focused design and criteria 2 specified a cross-functional design. Criteria 3 concerned authorization issues in a multi-level design and criteria 4 proposed integrating the CII-program into daily work. The following criteria 5 to 8 concerned the actual process within the program, as criteria 5 proposed encouraging divergent and convergent thinking for explorative and exploitative learning behavior (March 1991). Criteria 6 proposed an experimental design that encourage testing assumptions. Criteria 7 proposed a self-managing design that limited complexity for the participants. Finally, criteria 8 proposed awareness of organizational learning and knowledge processes (Crossan et al. 1999; Carlile 2002).

PROTOTYPES OF THE CII-PROGRAM

For the first applications of the CII-program, the prototype visualized a simple process where the participants contributed to clarifying and solving the problems and choosing methods for the problem-solving process. Figure 5 represents the planned process.

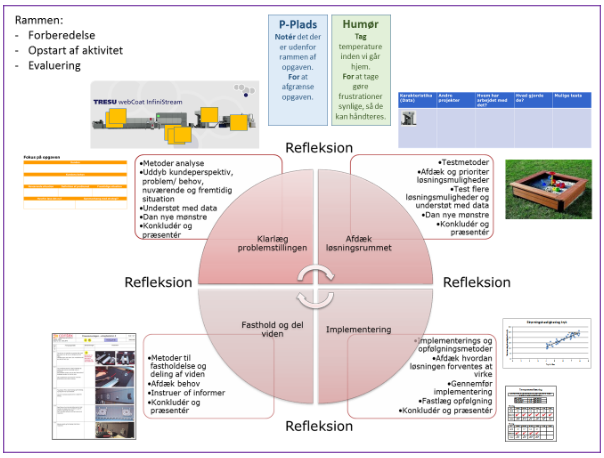

Figure 5. Illustration of the program used as the first prototype (text in Danish). There are four steps in the process: clarifying the problem, uncovering possible solutions, implementing, and sustaining and sharing knowledge.

The activity plan included hypotheses, expected results, and methods for measuring effect. The first CII-program application resulted in a board created to share knowledge on the current project. Although the project group was pleased with their work, they were not particularly explorative regarding testing problems with facts or considering various solutions. This meant that information on the board was scarce.

The second prototype of the CII-program followed the same agenda as the first prototype and added a storyboard visualizing the problem-solving process for the participants and other stakeholders. The second prototype used a large A0 sheet that functioned as a storyboard to direct the intervention process and contain findings of the problem solving. Each of the fields of the A0 sheet represent a step in a process to help participants examine and select problems and propose possible solutions. Figure 6 illustrates the second prototype.

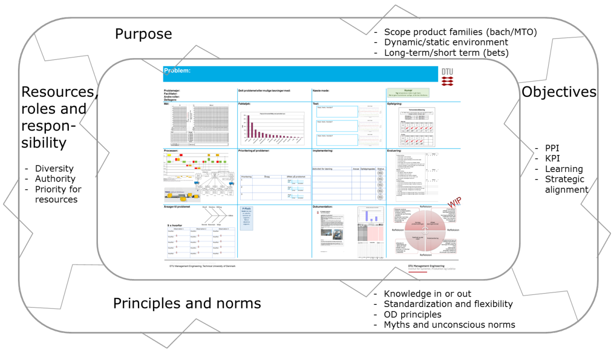

Figure 6. The second prototype clarified management scoping and visualized the problem-solving process on a storyboard.

The intention with the revised second prototype was to advance the testing of assumptions, especially those participants had about their colleagues in other functions. The goal was also to progress the process in order to reach the last two of four quadrants: implementation and sustain and share knowledge. Furthermore, the second prototype of the CII-program stressed the importance of scoping the problem-solving activities with management before initiating the activities and reporting outcomes to management afterwards. Figure 6 illustrates the scoping with a broken frame around the storyboard, as it could be necessary to renegotiate the conditions for solving the problems. In addition, the scoping specified management's role in relation to improving ETO processes.

THE FINAL CII-PROGRAM

The final CII-program combines problem solving practices in design thinking (Brown 2008) and creative problem solving (Osborn 1957; Tassoul & Buijs 2007). The CII-program comprises five steps: 1) Prepare (Understand), 2) Clarify the gap (Define), 3) Design Solutions (Ideation), 4) Implement (Implementation), and 5) Evaluate (Test), as shown in Figure 7. The CII-program aims to solve specific problems leading to gradual changes as part of daily development work.

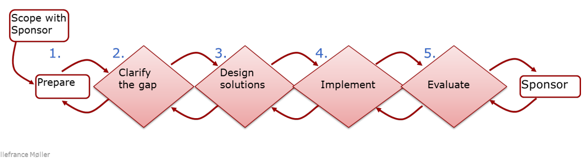

Figure 7: The five steps of the CII-program developed in a SME: Scope and prepare, Clarify the gap, Design solutions, Implement and Evaluate.

In step 1, prepare, the purpose of management scoping a task for applying the CII-program is to clarify intentions and ensure that the task makes sense to those involved.

Management representatives scope application of the CII-program together with a facilitator and an appointed manager. In the preparation, the management representatives form a common understanding of the current state of, for example, the ETO process arguing for the importance of the task. Management representatives also form a common understanding of what they want to achieve with the program, while they also clarify which factors influence the task and what resources are available. Expectations for the outcome of the CII-program are stated as targets, process objectives, and learning objectives. Scoping the task ensures that an appointed cross-functional group can work rationally on the task. The visualized scope illustrated in Figure 8 directed the problem solving in the cross-functional group.

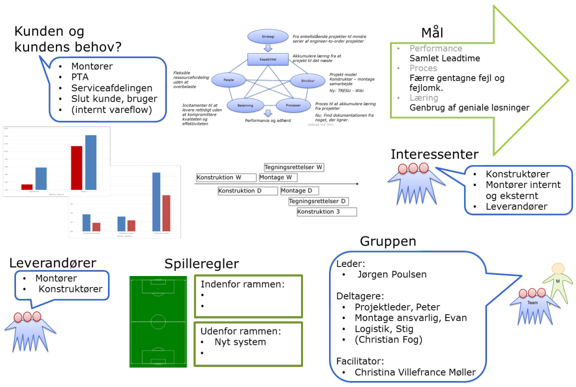

Figure 8. Management scoping the task (text in Danish).

Steps 2 – 5 comprise clarify gap, design solutions, implement, and evaluate. The following four steps in the CII-program aim at enhance participants' understanding of knowledge-sharing problems in ETO processes, explore more optional methods and solutions, select and implement a solution, as well as evaluate and share findings with others in the organization. The activities within each of the four steps support a rhythmic shift between divergent and convergent thinking. This means that, on the one hand, it is possible to propose several options (divergent) and select (convergent) options based on the design criteria. This divergent – convergent process is known as the double diamond or creative problem solving process (Osborn 1957; Tassoul & Buijs 2007).

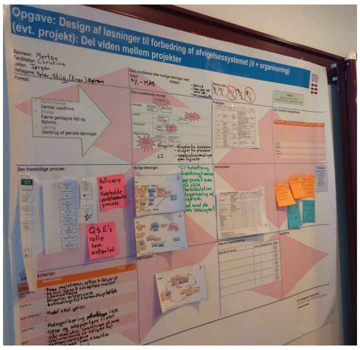

Figure 9. Storyboard for the final program containing the steps in the CII-program

Again, a A0 (shown in Figure 9) sheet functioned as storyboard helping the participants to keep track of the progress and findings in the CII-program. The steps formed a pulse of activities enabling divergent and convergent thinking (e.g. exploring possible root causes to a problem) followed by convergent thinking (e.g. prioritizing and selecting a cause).

DISCUSSION

Findings from the development process show that practitioners gain increased insight into cross-functional ETO-processes and the improvement process.

The fact that the design criteria, activities, and tools used in the CII-program are changed based on applications of prototypes does not itself confirm that prototyping is useful when developing a CII-program. However, in this case the following findings were gained from applying prototypes of the CII-program:

- Scoping application of the CII-program is a tool for engaging management in continuous improvement and innovation of ETO processes.
- Using storyboards helps participants and the facilitator focus on the task instead of each other.
- Participants on all levels and across functions gained insight into their ETO processes.
- Participants on all levels and across functions also gained insight into each other's work, challenges, and interdependencies.
- The program designer (the author in this case) gained valuable feedback regarding gaining momentum in the program.
- The program designer gained valuable insights into practitioners' difficulties in developing their processes as part of their daily development work.

Furthermore, it became evident that participants and facilitators (in this case the author) constantly had to work on both a product level and a process level. The participants focused on both the equipment they were designing and the ETO-processes. The facilitator focused on the CII-program as a product supporting practitioners' development of their ETO processes. In addition, the facilitator focused on the program development process. These observations are relevant to compare with classifications of learning levels made by Gregory Bateson (Bateson 2000). According to Bateson (2000), "learning" implies a change that can be progressive or regressive in nature. Second-order learning is the ability of learning to learn, which means that the learning achieved in a context can be transferred to another context to become increasingly better at solving problems (Bateson 2000). Learning to learn in a new context entails a use of this habit and requires the creation of a new habit and possibly breaking the existing habit (Bateson 2000).

CONCLUSION

This paper contributes an in-depth description of applying prototypes in a probe-and-learn process of developing a CII-program. Further research will include an organizational learning perspective of the learning process in the CII-program. An analysis will focus on the learning of integrating new organizational practices in daily ETO processes. Furthermore, research will comprise a similar development process in a large make-to-order manufacturing enterprise.

An interesting topic for further research could also be the study of paradoxical practices in the relationship between the Lean manager and the author as facilitator regarding the participatory process.

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More than 80 Danish manufacturing enterprises have joined forces with five universities, two technological institutes, and other educational institutions in an initiative called MADE (Manufacturing Academy of Denmark) with the overall purpose to help Danish enterprises find solutions for their industrial challenges. This paper contributes as a part of MADE and the SPIR (Strategic Platform for Innovation and Research) as Work Package 7 (WP7): "The "new" Manufacturing Paradigm".

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