EXPERIMENTAL VALIDATION OF A METHOD FOR SYSTEMATIC NEW DEVELOPMENT

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ABSTRACT

Creativity is an essential factor in the development of innovative products. 4 Step Creation (4SC) is a method for systematic ideation and can be used to enhance the new product development process. It aims to promote creativity in interdisciplinary teams and provides a framework for collaboration so that original ideas can emerge, laying the foundation for innovation. At the same time, the method can be used for continuous improvement of existing systems. In this contribution 4SC is used in a design method experiment following the Design Method Validation System (DMVS) to validate design methods in product development. The experiment was carried out at PAD2022 International Summer School on the example of a vacuum cleaner robot. Findings show, that the developed method promotes transparency, traceability of ideas and thus communication in the team. It also facilitates the integration of different stakeholders in the ideation phase. The experiment also shows that the DMVS is well suited for planning, conducting, and evaluating design experiments.

Keywords: Design methods, Open innovation, New product development

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1 INTRODUCTION

Emerging technologies, changing requirements and shorter product lifecycles are main drivers of today's markets and lead to innovation pressure for existing and new businesses. They need to develop new and innovative products considering those surrounding factors. Creativity is an essential factor for innovative product design (Zhao et al., 2021). In order not to leave creative work to chance, but to bring it about in a targeted manner and to make it both systematic and reproducible, appropriate underlying conditions must be provided. 4 Step Creation (4SC) was developed to support the joint, systematic development of artifacts capable of innovation and thus to create the basis for the development of new successful products (Küchenhof, 2021). 4SC provides a new approach to combinational creativity research based on recent advances in design thinking (Kwon et al., 2021; Zhao et al., 2021; Childs et al., 2022). The methodological approach developed is intended to provide a consistent and formal model for guided creative thinking, whether for creative ideation or new product development activities. 4SC was developed with the help of several student theses and has been applied and further developed within the online project *Collaborative Ideation - Design Methods going Digital!* (Küchenhof and Bickmeier, 2021) as part of the Hamburg Open Online University (HOOU) (Classen, 2022). Within the project, 4SC was used to guide a shared ideation process and support complex societal problem solving using the example of plastic waste in urban environments.

In order to validate the developed 4SC, it was applied and explored in the form of a design method experiment during PAD International Summer School on Product Architecture Design 2022 (PAD2022). The summer school is a intensive learning course for PhD researchers with multidisciplinary topics on product architecture and takes place every two years with sponsorship from Design Society (Sankowski et al., 2019). In 2022 the summer school was hosted by Chalmers University of Technology and took place at CampX - Startup Accelerator by Volvo Group in Gothenburg, Sweden. At PAD2022, 4SC was used in the research workshop *New Development of Modular Product Architectures* with the aim of generating creative ideas and promoting innovative product architectures using the example of a robot vacuum cleaner. Applying Üreten et al. (2020)'s Design Method Validation System (DMVS), the workshop was used to set up, conduct, and evaluate a method experiment with the aim to validate 4SC.

In this contribution, the procedure of 4SC and that of the DMVS and the validation experiment are presented. Subsequently, the results of the method experiment are shown and discussed. Section 2 provides a theoretical foundation related to innovation and creativity. Also, the DMVS for method validation is presented. 4SC is presented in Section 3 and the application of the DMVS onto the 4SC follows in Section 4. Finally, the experiment and implications for the innovativity of product architectures are discussed and an outlook on further method adaptations and research directions is given in Section 5.

2 THEORETICAL FOUNDATION

Modular design offers advantages for product, production and organizational systems with its possibilities of great combinability and extensive technology exploitation. In terms of innovation, the answer is not obvious, as modularity, for example, can facilitate imitation Mertens et al. (2022). For the development of modular product families, the Integrated PKT approach for the development of modular product families provides a toolbox for modular design considering the external offer variety as well as the internal product and process complexity (Krause and Gebhardt, 2023). Basic terminology is adopted from here and tools from it such as a Tree of External Variety, which represents product features, and a Module Interface Graph, which represents product structure, are used in the design method experiment.

2.1 Innovation and creativity

There are different understandings of the term innovation. A common comprehension is that innovation is both the introduction and the market success of a novel, advanced solution to a specific problem (Ehrlenspiel and Meerkamm, 2013). A distinction is made between different types of novelty. The solution can be new globally, within an industry, or within a company. Furthermore, the novelty does not necessarily have to be a product, but can also be a process that advances the marketing or organization of the company's activities (Ehrlenspiel and Meerkamm, 2013). Alsp, different frameworks for linking product architecture and innovation exist. Henderson and Clark (1999) assess innovation in the

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dimensions of components and organizational linkages. Lynn and Akgün (1998) sort types of innovation projects on the degree of technical and market uncertainty. Here, incremental innovations build on existing knowledge while the greatest degree of uncertainty is associated with radical innovations.

The ability to innovate can be promoted by creating new stimuli. For example, new experiences, input from outside and creativity techniques can break old patterns and thereby increase the chance that new ideas will emerge (Ehrlenspiel and Meerkamm, 2013).The combination of knowledge and creativity results in creative performance, which can be increased through targeted knowledge acquisition and the use of creativity techniques (Gausemeier et al., 2001). According to Zhao et al. (2021) creative idea generation is the first and most important step in innovative design.

The task of innovation management is to provide suitable approaches, methods and processes that create a framework for the development of innovations so that new ideas and concepts are continuously developed and the creativity of the developers is promoted (Deigendesch, 2009). The Double Diamond provides a framework for the development of innovations, which contains phases of divergence and convergence (Kwon et al., 2021). Divergence serves intuitive thinking and to open up the solution space by collecting ideas. In convergence, discursive thinking is addressed and the solution space is compressed again with analytical thinking and idea selection (Childs et al., 2022). Other well-known design thinking methods are the IDEO 3i model and Stanford s.school's five-step design thinking model (Kwon et al., 2021). Appropriate metrics are needed to evaluate developments also in the ideation phase. Innovation measures can be the number of ideas (idea fluency) or the quality of ideas (Mirabito and Goucher-Lambert, 2022). Goucher-Lambert et al. (2020) estimate the impact of adaptive stimuli on design outcomes considering novelty, feasibility and usefulness of design concepts. Novelty describes the uniqueness of a solution, considering if it pre-existed or not. Feasibility is rated depending on whether the solution can be implemented or technology to create the solution does not exist yet. Usefulness describes whether the solution is helpful beyond the status quo or if there are implicit problem constraints (Mirabito and Goucher-Lambert, 2022).

2.2 Design method validation system

The DMVS is a procedural system for design method validation focusing on an objective and reproducable study design. It has been successfully tested in prior studies (Üreten et al., 2017; Üreten and Krause, 2017; Üreten et al., 2020). The DMVS bases on fundamentals from experiment design in psychology to fulfil needs in product development and consists of the phases planning, data collection, data analysis, discussion and reflection and parallel documentation and reporting (Üreten et al., 2020). The planning includes several steps of preparation that is required before data collection. The study goals, research question or hypothesis to be tested in the experimental study are formulated. The design method for experimental validation needs to be decomposed into its individual steps to identify suitable parts of the design method for conducting the validation experiment. Those are the phases that are critical and have high importance in the design method procedure. After having identified critical steps, adaptations to the design method can be developed. The adaptations are required for the definition of the independent variable. The dependent variable can be defined in accordance with the validation dimensions applicability, usefulness and acceptance. The planning also includes the experimental setup, which involves the practical conduction of the experiment, the participants, an adequate task design and theoretical design features, such as the factors and levels and specific experiment conditions, choice of location, timing and materials (Üreten et al., 2020). Data collection describes the gathering of data during the experiment design as well as from pre- or post-studies. Data can be gathered during the conduction of the experiment within the working materials and documentation sheet. Also monitoring of participants is possible or interviewing attendees afterwards. Data analysis is usually performed on the basis of different channels and sources. A more extensive database can provide more information, but can also lead to a loss of focus. The analysis of the data leads to the discussion of the results. A distinction between the results from the experiment itself, but also the design method that is analyzed in terms of the design of the experimental validation is necessary here. The discussion and reflection phase is crucial for the validation. Formative feedback can help to identify optimization potential within the developed design method. The documentation and reporting is a continuous activity during the entire validation process using the DMVS. The goal is to generate transparent documentation that provides a reproducible design method validation process (Üreten et al., 2020). Comparability is improved by a standardized procedure for documentation. In the following, 4SC will be presented and then the DMVS will be applied to it.

3 4 STEP CREATION

4SC can be used for systematic ideation and to enhance the new product development process (Küchenhof, 2021). It aims to promote creativity in interdisciplinary teams and provides a framework for collaboration so that original ideas can emerge, laying the foundation for innovation. At the same time, the method can be used for continuous improvement of existing systems or represent networked knowledge. It is designed to help move from the space of the known to the space of the unknown, bringing forth new knowledge within the process. The four steps *Define & Gather*, *Tag & Cluster*, *Vary & Combine* and *Evaluate & Select* are designated for this purpose. The method is depicted in Figure 1.

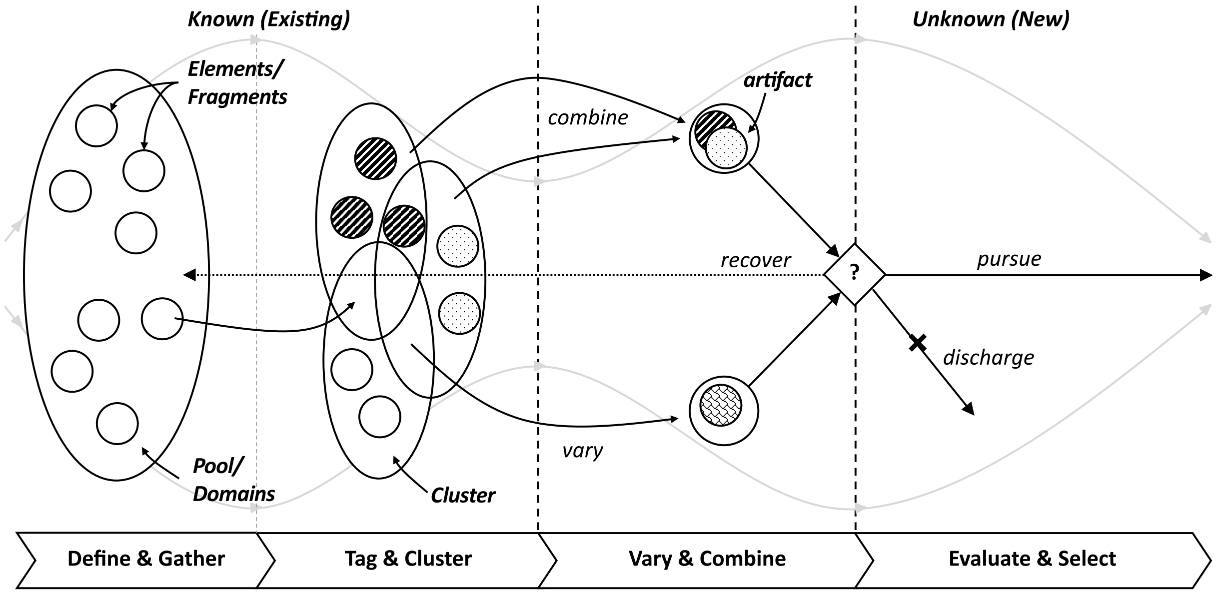

Figure 1. 4 Step Creation (Küchenhof, 2021).

Step 1: Define & Gather. Under a specific question, the relevant design domains are determined respectively the pool is *defined*. This can be the problem and solution space for innovative problem solving as shown in Küchenhof and Bickmeier (2021) or the domains of product properties, functions, operating principles or components relevant for product architecture design according to Krause and Gebhardt (2023). Within the selected domain, information is *gathered* and relevant elements are identified, which are to be worked with in the further procedure.
Step 2: Tag & Cluster. The elements collected in the domains usually differ from each other and can be described in terms of their difference with certain (feature) characteristics. Keywords are used to *tag* the elements in terms of their characteristics, properties or other aspects. *Clustering* can be done by classification (e.g. using the keywords). The variety of different clustering possibilities depends on the classification characteristics (for example the chosen keywords). The same and the same rarely result in something new. For innovative ideas, the individual clusters must therefore have a certain degree of difference from one another. To generate diverse and differentiating artifacts, change mechanisms are used (e.g. ideation methods).
Step 3: Vary & Combine. New artifacts can be created by *varying* individual elements or changing their relation to each other. As a further mechanism the combination of changed elements or also the new *combination* of known, however so far not linked elements is suitable. With this step the space of the so far known (known, existing) is left.
Step 4: Evaluate & Select. The created artifacts are *evaluated* in the last step. When considering different criteria, multi-criteria evaluation procedures are suitable. Non-novel or non-useful artifacts are returned to the pool of elements (recover) to be further developed in further cycles. Non-novel and non-useful artifacts are discarded (discharge). Artifacts that meet the defined criteria, e.g. “novelty” and

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"usefulness", to a high degree are considered potentially innovative and should be *selected* for further development steps, e.g. concept or product development (pursue). These artifacts belong to the solution space that is still unknown at the beginning (unknown, new) and are capable of innovation.

4 APPLICATION OF THE DMVS ONTO 4SC

A design method analysis experiment is to be carried out to validate the 4SC method. Therefore, the DMVS was applied to the 4SC method, following the phases of DMVS: planning, data collection, data analysis, and discussion and reflection as presented in Section 2.2 and a design method has been carried out. The detailed planning is described in the following.

4.1 Planning

In accordance with the DMVS, various aspects were taken into account during the experiment preparation, including study goals, hypotheses, method adaptation, participants, task and experiment procedure.

Study goals: The main goal of the study was to analyze the impact of adaptations in the design method. Specifically, the influence by the difference in the implementation of the idea generation phase with methodological support of *Step 2: Tag & Cluster* and *Step 3: Vary & Combine* from the 4SC method or respectively without. The aim also is to proof the stated hypotheses.

Hypotheses: The hypotheses that are stated within the study are, that (1) the conscious variation and alteration of solution elements is supported by *Step 2: Tag & Cluster* and *Step 3: Vary & Combine* of the 4SC method and (2) the systematic development of ideas and their linkage to product architecture fosters acceptance and feasibility of emerging ideas.

Method adaptation: The design method was decomposed and analyzed in detail. Essentially, two critical and relevant steps of the 4SCM are identified, which represent a special lever for the novelty of concepts and contribute significantly to the added value of the design method. The idea generation phase can be divided into the *Step 2: Tag & Cluster* and *Step 3: Vary & Combine* of the 4SC method. Accordingly, two groups are formed in the method experiment. The control groups work according to the specifications of the 4SC method and perform *Step 2: Tag & Cluster* and *Step 3: Vary & Combine*. Meanwhile, the experiment groups are to develop new product concepts through free brainstoming.

Participants: The participants are young researchers attending PAD2022. The venue of Volvo CampX is a large presentation room in the building. To bring all participants to a common level, a consolidated state of the art in the research area of product development methods with a focus on product architecture design and modularity is presented to the participants during the week.

Task: The example of a vacuum cleaner robot used in the exercise is already presented to the participants in a previous workshop. The participants receive more detailed information about the product architecture in form of of a Tree of External Variety showing the relevant product features and a Module Interface Graph, representing the product structure. Additional input for the exercise for all groups is a trend map and a list of module drivers. The task is to develop an innovative product concept for the vacuum cleaning robot.

Experiment Procedure: The procedure of the design experiment is shown in Figure 2. It is used for the structured data collection during the experiment.

Phase A - Introduction: As in the other workshops during PAD2022, a keynote speech is given to all participants to introduce the topic. This is intended to provide participants with a common understanding of the topic and a shared level of knowledge.

Phase B - Group work: Next, the participants are divided into four groups of four to five people in each group. The two control groups follow *Step 2* and *Step 3* of the 4SC method and the two experimental groups follow a free ideation process. The groups are spatially separated to ensure independent development of ideas in the groups. The experimental groups are supervised by an experienced researcher who coordinates time and answers questions as they arise.

0) The control groups are supervised by the inventor of the method to be tested and receive an introduction to the 4SC method and a manual in which the steps are explained in detail.

1) All groups familiarize themselves with the materials. Both groups are given 5 minutes to review the distributed material. *Step 2* and *Step 3* of the 4SC method are to be performed by the control groups. In this example *Step 1: Define & Gather* is conducted before and serves as input.

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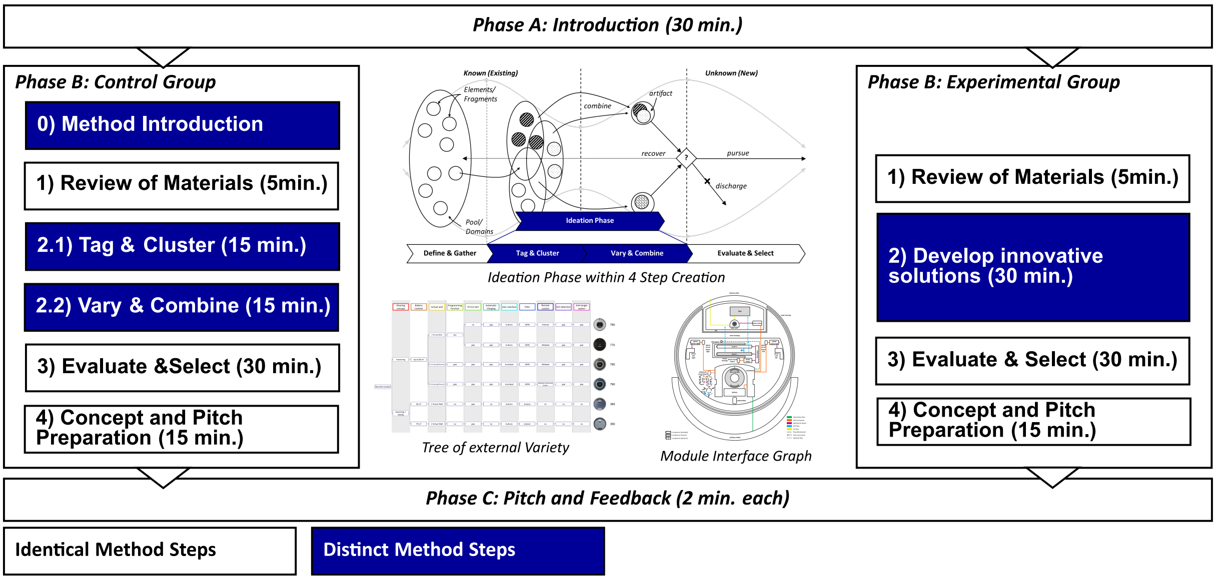

Figure 2. Procedure of the design method experiment.

2.1) In the next step, the control groups have 15 minutes to conduct *Step 2: Tag & Cluster* of the 4SC method and tag the defined elements. The keywords are freely selectable. It is suggested to use trends or module drivers to mark the elements. It is also permissible to assign several keywords to one element. Based on the assigned tags, the product features or components are grouped into clusters. If an element has several tags, the clusters overlap. The elements are numbered for transparent documentation.
2.2) To generate diverse and differentiating product features, the control groups have another 15 minutes to apply *Step 3: Vary & Combine*. The derivation of a new product feature from an existing one is indicated by a dash at the numbering. Another mechanism is the combination of already known product properties. New combinations are marked with the code numbers of the original elements. It is also possible to combine modified elements with each other or with other known elements. The newly created artifacts are marked with capital letters for traceability.
2) The experimental groups have 30 minutes to freely develop innovative solutions or partial solutions.
3) In *Step 4: Evaluate & Select*, the found solutions are evaluated. Both teams have 10 minutes to do this and should use the evaluation portfolio.
4) During the last 15 minutes the participants are to bring together an innovative overall concept and prepare the final pitch.
Phase C - Pitch and Feedback: In the final phase C of the experiment, each group has 2 minutes to briefly pitch their concept, i. e. to present their procedure during the design experiment and the selected solution or overall concept. Afterwards, the different concepts and the approaches to finding a solution are discussed in plenary. Finally, method feedback sheets are distributed on which the groups can record what has worked particularly well and where there was still room for improvement.
Validation Dimensions: The dimensions of validation include the usefulness applicability, and user acceptance of the method.
For the data collection, a mix of research tools was used. In particular the data was taken from the elaborated results following the experiment design in Figure 2. The main data used for the validation of the usefulness of the method were the respective generated results during the ideation phase and the evaluation phase. Group feedback was gathered in writing after the pitch. The participant's feedback is relevant especially for validation of the applicability and the user acceptance of the design method. Major advantages as well as problems during conduction of the exercise were recorded in writing on method feedback charts.

4.2 Data analysis

As an introduction to the topic, a keynote speech was given on the topic of new development of modular product architectures with special considerations in the early phase of development. No questions were asked on demand.

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During the ideation phase, control group 1 developed nine ideas in total. The group first listed and numbered the product features. This was linked to trends from the trend map in *Step 2: Tag & Cluster*. The group selected the three trends *Intelligence*, *User* and *Function*. In *Step 3: Vary & Combine*, the group plotted the combinations and derivations that resulted from linking trends and product features. Sketches of some individual ideas are shown in Figure 4 on the left. This resulted in solutions such as automatic dirt disposal, remote spotlight cleaning and another idea that was the remote butler, which for example receives mail or packages when one is not at home. In *Step 4: Evaluate Select*, the team had to evaluate the partial solutions that emerged. Idea I was considered technically infeasible, therefore solution D was selected with the same level of novelty and utility as it was considered feasible. All methodological steps in their application by the control group 1 is shown in Figure 3.

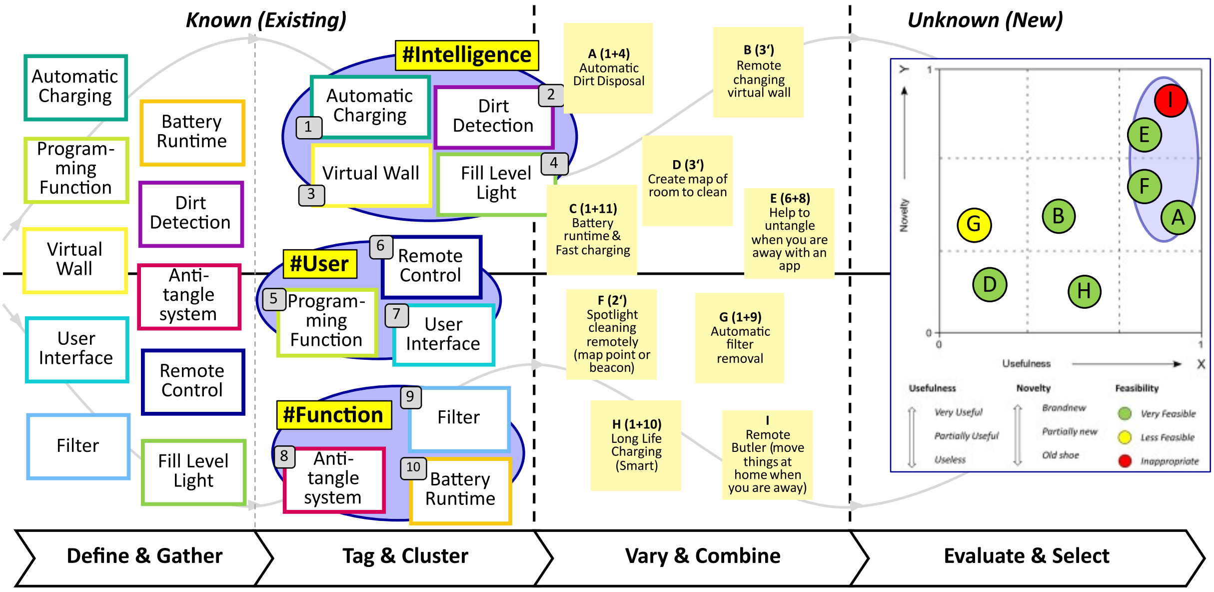

Figure 3. Results of control group 1 using the 4 Step Creation method.

Control group 2 developed three ideas. The group chose to change components to enable new features. In *Step 2: Tag & Cluster*, the components were linked to change drivers. In *Step 3: Vary & Combine*, the necessary changes to the components were entered. For example, the mainboard needs additional hardware and software for communication, the bin needs sensors, and the housing needs a camera to realize the concepts of 4D (Data Driven Dirt Detection), CC-TVac (moving surveillance camera) and remote vacuuming. In the evaluation phase control group 2 chose the 4D concept with highest rating concerning usefulness, novelty and feasibility.

Experimental group 1 has developed a total of six ideas. The quiet robot with vortex generator has more power but is more silent, the 2-in-1 vacuum cleaner has a detachable hand-held vacuum. The green robot is made of recycled components and the rolling robot moves by rolling and vacuuming while moving. Another idea was to connect it to other IoT devices to do other tasks such as feeding the pets when one is not at home. The last idea was an AI-based cleaning robot that continuously learns and can perceive its surroundings in a different way. Experimental group 1 was evaluated its partial solutions and merged them to a final concept Vacuum X-VaX which integrates the 2-in-1, AI-based cleaning and vortex optimized sound emission which can be seen in Figure 4 on the right.

Experimental group 2 developed nine ideas during the idea generation phase. Omnidirectional cleaning reaches previously unreachable areas by adding side brushes. Similarly, the idea of integrating a high side brush. Improved threshold and hair removal (especially for pets), noise reduction through other materials or active noise cancellation, or digital integration through a suitable user interface and automatic dirt discharge are other ideas that emerged. During the evaluation, concepts for noise reduction were considered most promising. The final concept proposed was a combination of active noise suppression and rubber components for damping.

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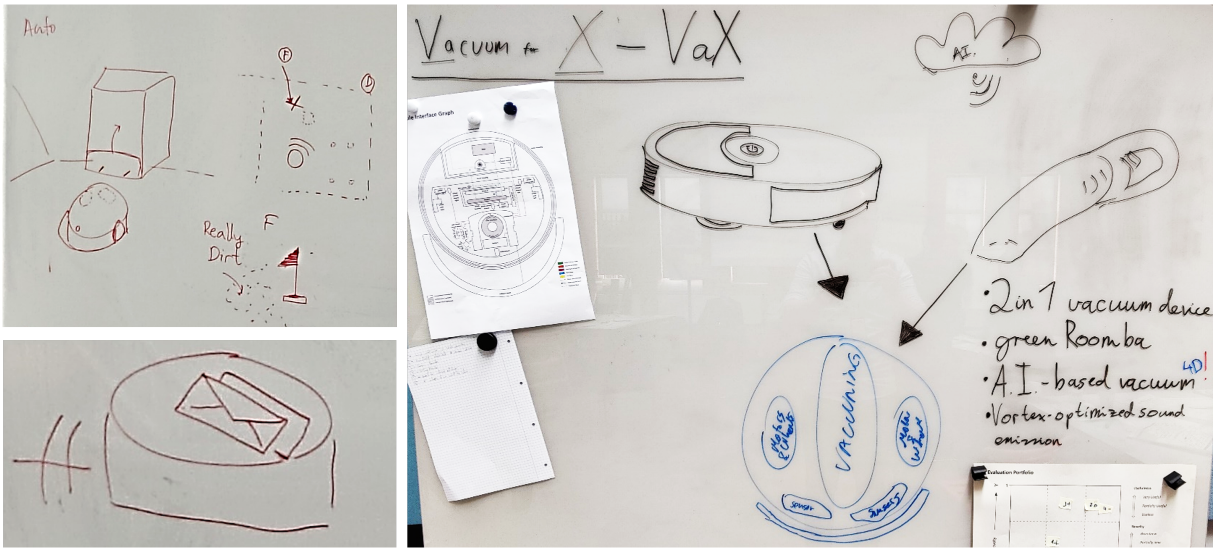

Figure 4. Left: Idea sketches of control group 1; Right: Final concept Vacuum X-Vax of experimental group 1.

The different approaches and the solutions developed in the groups were then presented to each other during the pitch. In the final step, the group's feedback was then recorded on distributed method evaluation sheets.

4.3 Discussion & reflection

The discussion and reflection of the conducted design method experiment respects the validation dimensions usefulness, method acceptance and applicability. The usefulness could be shown by analyzing the recorded data. Applicability and user acceptance are assessed using method evaluation forms, which is presented in the following.

Control group 1 states that the flow of steps makes sense and guides the innovation process well. They came out with ideas and were able to improve them and join them using *Step 2* and *Step 3* of the 4SC method. The evaluation portfolio for *Step 4* was considered helpful. The problems they encountered understanding were, that the wording of the methodology was not easy for new users of the method and that more time is needed to fully understand the method. Also, examples of how to apply the methodology in each step would be helpful. The trends stimulate the ideation process, but they are a bit too general, and linking them to customer requirements would be beneficial.

Control group 2 also found the trends were helpful for idea generation and the evaluation portfolio was easy to use. Structuring the idea generation can promote its emergence and avoid too long discussions. The documentation of the idea generation in each step increases the comprehensibility. Later steps were rated as easier to understand and apply than earlier method steps. It was also mentioned as a possibility for improvement that a consistent wording is important and a definition with the distributed material would be helpful. On the methodological side, the concepts of convergence and divergence were not as well understood.

Experimental group 1 found that freedom in brainstorming encourages more radical innovation and thinking outside the box. They evaluated the trends as stimulating and the introduction as useful for fostering a common understanding of the topic. They rated their process as chaotic compared to the more structured approach in the control groups. Without guidance, they were slower in the beginning and did not know exactly how to adequately use the distributed materials.

Experimental groups 2 emphasized brainstorming because it is common practice and they are used to it. The freedom during ideation is useful for developing a wide variety of interesting concepts. The status quo of the product structure was rated useful to promote the creative process. However, a high degree of freedom implies a high degree of uncertainty in the results in terms of the technical feasibility of the concepts as could be seen in the evaluation portfolios. In addition, structuring the tasks in uncertainty is not easy at the beginning and rather chaotic. However, the team was able to quickly structure itself.

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All teams were able to develop ideas with a certain degree of innovativeness, with regard to the criteria presented, and to create a final concept. The method steps *Step 2: Tag & Cluster* and *Step 3: Vary & Combine* were intended to support combinatorial creativity, which worked well in the control groups. In Idea I, control group 1 also discovered a solution that they could not assign to the features of combinatorics or deduction. However, the solution was found to be the least feasible. The number of ideas was high in all groups except control group 2, that developed only three ideas. Since the goal was not to have many ideas, but to develop innovative concepts, this is not considered critical with respect to the task. However, it is recommended to have many ideas first to create a broad idea base. The experimental groups had many ideas, but the lack of guidance cost time to improve the solutions found. Therefore, the feasibility of the control groups' solutions may have been rated higher, also in the method feedback sheets. The material handed out, especially trends and product structure, was helpful for new product ideation. The trends could be made more concrete or described in a case-specific way, maybe with detailed comments.

Overall, it can be said that hypothesis (1) can be verified, as the control groups were able to vary and intentionally change the defined elements. The documentation of the ideation process enables traceability, which promotes conscious idea development and decision-making in the group. Hypothesis (2) can also be confirmed, as new product features can proceed to marketing, and improvements and specific changes to the product structure and corresponding components can enter the subsequent product development process. As a result, the ideas and resulting concepts are closer to the customer or closer to the developer. In this case, the experimental groups tended to create less practicable concepts, as they deviated quite far from the present product. For a completely new development, though, a free generation of ideas could be a decisive advantage. Therefore, such a phase should be included in the design process. 4SC is understood more as a superordinate framework. Even if the ideas were initially found freely, they should still be documented and can ideally be incorporated in the 4SC method. One group experiment for two groups may not be sufficient to draw meaningful conclusions but the overall level of results is considered high, as the participants showed a good basic knowledge and a very good understanding of the new method. The biggest limiting factor was time, as each workshop at the summer school is limited to three hours.

5 CONCLUSION & OUTLOOK

The validation of design methods is essential in method research to ensure essential aspects such as usefulness, applicability and acceptance of a method. The DMVS recommends experiments for validation, as causal relationships can be identified and reproduced. Here, the DMVS was used to validate the developed 4SC with focus on two essential method steps for the idea generation phase. Through the results in all groups, it could be shown that useful ideas can be generated and evaluated with the proposed ideation framework. The group feedback shows the acceptance and applicability of the method and parts of it. It could also be shown that the two critical steps in the ideation phase within 4SC support ideation in terms of combinatorial creativity. The methodological approach promotes transparency, traceability and communication in the team. Therefore, it also facilitates the integration of different stakeholders in the ideation phase. The experiment showed that working in the areas of the market with product features or in engineering with product components for changes and upgrades can improve the acceptance and technical feasibility of concepts. It has also been shown that the DMVS is well suited for planning, conducting, and evaluating design experiments. 4SC will be further developed based on the study results presented here, and additional applications are planned to establish the approach. As this was the first design method experiment using 4SC in the context of product architecture, further studies will be necessary to optimally support the new development process. Moreover, the product example of the vacuum cleaner robot is an existing solution that is already familiar to many. The application for a complete new development is therefore of high interest, especially for a real product development case.

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