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Storyboards as an Engineering Tool for Extraction of Functional Requirements

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Abstract

In new product development courses, engineering students are introduced to the tools for addressing the functional or technical issues of the product. Problems arise when they need to empathise with the user to better understand how the product can be used in different contexts. To address this problem, we propose the use of storyboards as a tool to explore user behaviour and to clarify functions of the future product. The study results confirmed that storyboards are a suitable tool for understanding user-product interaction, however, the several problems encountered by the participants were outlined.

Keywords: *new product development, user-centred design, design education, storyboards, functional requirements*

1. Introduction

Identifying product requirements is one of the most important steps in the engineering design process. As with all design problems, effective, accurate and complete specification of design requirements is essential if design engineers are to deliver a high-quality design solution within a reasonable cost and time frame (Wang & Zeng, 2009). Often product requirements, even in the context of mechanical engineering, include different aspects, e.g. marketing, design, manufacturing and current trends (Eppinger et. al. 2003). Therefore, functional requirements cannot be defined independently as they are linked to business requirements, marketing, sales requirements, user requirements, etc. The requirements gathering process requires effort, knowledge of the product and the ability to gather the right information from available sources (e.g., R&D department, customers, Internet research, etc.). This process might be easier if the product line is already established because the market segment is already known. At the beginning of the new product development, the referential data does not exist, and a lot of information is fuzzy and unknown. Before functional requirements are defined, the main issues and concerns related to the use of currently available products are usually defined. Eppinger et al. 2003, mentions that the concept development process begins with the identification of customer needs, which are later transformed into target specifications. Specifications are the translation of customer needs into technical terms (Ullman, 2003). The process of identifying customers and their needs requires using a variety of methods and tools. In engineering design, for this purpose Kano model and QFD are used (Akao, 1990). Fiorineschi et al. 2020 proposed a structured tool capable of assigning different requirements to specific functions and distinguishing between design desires and requirements in the form of a generalized matrix. To determine customer needs, Eppinger et al. (2016) suggest collecting raw data from customers by conducting interviews and focus groups and observing the product in use. Engineering students do not have the resources to conduct extensive surveys or reach out to potential customers for the product they are developing as part of their majors. When developing new customer-oriented products, it is necessary to integrate tools that can explain user behaviour. Therefore, many professionals from different design fields use user-centred design tools such as storyboards as a visual tool to capture user behaviour characteristics in a few images (Birchman & Sadowski, 2006). Storyboarding is a creative technique to represent the user's behaviour and interaction with the product. It can be used at various stages of the problem-solving process (Higgins, 1995). Storyboards can be created quickly without many resources. Often when the engineers receive a design assignment, technical problems are described in a written form, leaving the engineering team with insufficient information. Textual descriptions make it difficult for engineers to see exactly where user complaints relate to the use of the product. Sketches, pictures, and other visualisation techniques are therefore helpful in providing a more complete representation of the project task. To test and implement novel teaching methods, we used storyboards in the early design phase. In this study, we investigate the potential of the storyboard method for extracting functional requirements for the new product design in engineering courses. Student design teams participating in this study experienced product design process through project-based learning (PBL) as part of an ELPID project. During the course, students were introduced to storyboards and other brainstorming tools. In the ideation phase, they were asked to use storyboards to explore how users behave in a particular context and how this leads to product requirements.

2. Project-based NPD process

Through project-based learning, students learn diverse design skills by solving real-world problems. With this approach, the student engagement is increased as they move from passive learners to content creators, known as "learning by doing" (Colbran et al. 2014). The ELPID (E-Learning Platform for Innovative Product Development) project is based on long-term experience with virtual collaborative NPD (New Product Development) courses and design education research gained through continuous delivery of project-based learning courses by six European universities forming an academic virtual enterprise together with selected industrial partners (Vukašinović and Pavković, 2017). The main objective of the project is to develop, test and consolidate a design education methodology that leverages the virtual mobility and collaboration of design and engineering students and academic staff to foster the innovation, development, and realisation of new industrial products. Students form virtual teams of 8-10 members and work on real-life situations. The entire design process is continuously supported by an industrial partner (company) during the semester (Žavbi and Vukašinović, 2014). Elements of the course include: (1) project definition - in consultation with the industry partner, (2) lectures tailored to the specific requirements of the current year project and evenly distributed across the partner universities, (3) project work supervised by academics and the partner company with three distinct phases and review points, and (4) the final workshop which includes virtual prototyping, final presentation, and exhibition. Each NPD phase includes various supporting design and communication tools and instructions for students. Coaches guide each student team while professors lecture on relevant topics. The partner company provides the definition of the project task, which is based on a real-world problem to be solved by the students. The company partner is involved in the project from the beginning to the end of the course, advising students with real-world examples and other information. The basic methodology of the design process was adopted from Pahl & Beitz (Pahl et al. 2007, Roozenburg and Eekels, 1995), but shortened to three development phases because the project duration is limited to one semester of study. The first phase is a fuzzy front end of the design process, where the definition is set from a problem in the world to a design problem. In a second phase, students translate the design problem into product concepts. Finally, the third phase involves developing a selected concept into a virtual prototype. Depending on the type of project, the first phase can range from clarification of the task to full Fuzzy Front-End (FFE) problem identification. In case of the FFE start of the project, the end product is not clearly specified at the beginning. Once the product is defined in terms of required features and other requirements, teams enter the concept generation phase (Čok et al. 2018). The use of requirements that are not well defined and structured may cause an increase in product development time or even non-acceptance by customers, generating extra costs and delay in placing the product on the market (Laksch, 2019).

3. Storyboards in the design process

Understanding user needs and evaluating the designs have been the key part of user-centred design (UCD) process and designing for good user experience leans on the same principles (Roto et. al, 2009). UCD is widely used in the software development industry, especially in the context of UI design (ISO/TR 16982: 2002). Parallel to UCD in computer science, there are design engineering initiatives that focus on users in product development, such as the Design Society SIG -Human Behaviour in Design, which apply similar principles in design research (Lindeman, 2003). Following the principles of interaction design, user-centred design is divided into two parts, with designers using a mix of investigative methods and tools (e.g., surveys and interviews) and generative methods (e.g., brainstorming) to develop an understanding of user needs (Interaction Design Organisation). An initial phase of early concept development is referred to as formative, discovery, exploratory, or generative (Hanington, 2007).

In the exploration phase, engineering students are introduced to various brainstorming techniques that facilitate idea generation in early design phases. The most common methods used for idea generation in design classes are: Brainstorming, Method 6-3-5, Gallery Method, Brainsketching, Wordwriting, Mindmaps, Synectics, Blackbox, 6-3-5, SCAMPER, Design by Analogy, Question Storming etc (Linsey et al. 2005). The motivation for using a particular method may be a personal preference based on the skills that a particular technique requires. The brainstorming techniques differ in context and in the way they are applied. They can be used individually or in a team. Moreover, creativity can be considered at three different levels: individual, team, and organizational (Chamakiotis et al. 2010). Considering the fact that methods are used in student teams, there are other variables that could increase creativity. Team interaction can lead to better ideas because teams are about combining and integrating the contributions of multiple people to create new knowledge and insights (West 1990). It is also important how ideas are shared and communicated within the team. Smith (1998) found that ideas that are presented visually are more likely to inspire new ideas. Sketches have been shown to be a more effective form of representation for developing new and high-quality ideas than text. Regardless of the design problem, graphic representations received higher average metric scores and were ranked as the more expressive language (McKoy et al 2001).

Storyboards are a valuable aid to the designer in this task because they provide a common visual language that people from different backgrounds can "read" and understand (Corrie van der Lelie, 2005). Storyboards are used not only to discover the interactions between users and products or systems, but also to understand what functions the product has and what parts it is composed of. Industrial designers and marketers use user personas in combination with a specific scenario to better understand the profile and daily habits of users (Cooper, 2004). Creating storyboards to better understand potential users requires a high level of designer's empathy. McDonagh (2006) describes empathy as "the intuitive ability to identify with other people's thoughts and feelings - their motivations, emotional and mental models, values, priorities, preferences, and inner conflicts". So-called 'empathic design' seeks to get closer to the lives and experiences of users (perceived, potential or future) in order to increase the likelihood that the designed product or service will meet users' needs (Koskinen et al. 2003). By observing users or imagining their behaviour, engineers can identify critical points of interaction between product and user and discover opportunities for improvement. However, the concept of using storyboards by mechanical engineering students is not widespread. It is important to invest sufficient efforts to find as many ways as possible to identify customer requirements. Once customer requirements are defined, they must be translated into specifications that are "the voice of the engineer." These specifications are the reformulation of the design problem in terms of parameters that can be measured and have target values. Without this information, engineers cannot know whether the designed system will satisfy the customers (Eppinger et al. 2003). It is important that students learn what tools and methods they can use to identify the needs of customers, and that they have the ability to empathize with the group of users with whom they are not familiar (e.g., the elderly). After defining the target users, it is a matter of determining what should be designed (Ullman, 2003).

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4. Methodology

The main objective of this research was to find out if the storyboard method helps students in defining and extracting functional requirements. The conducted case study involved virtual student teams working in a PBL course on product design. The course was organised as a collaboration between four universities and included allocated student teams. Five teams, consisting of eight team members, were mechanical engineering students and worked on product design task proposed by a household appliance manufacturing company. In the initial ideation phase, students had to use storyboards to identify customer pains and concerns in using the current products, and then use them to derive potential functional requirements for the future product. Later, students were asked to complete a questionnaire to get their opinions about the tools and methods used in the initial product development phase.

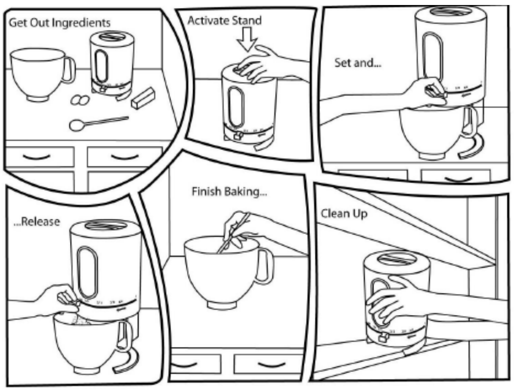
4.1. Participants

Three female and 37 male students participated in the ELPID course, both undergraduate and graduate levels. Each team consisted of two members from each institution (University of Zagreb, Politecnico di Milano, University of Ljubljana and TU Vienna). There were 40 students in total, but only 25 filled in the questionnaires. Students were asked to complete the questionnaire at their own discretion. Completion of the questionnaire was not mandatory. They were all mechanical engineering students between the ages of 21 and 25 from Austria, Italy, Croatia and Slovenia.

The gender distribution was: 24 males and 1 female. Age distribution 19 -21,5(20%); 22-24,15(60%); 24-29, 5(20%). Number of participants per country: Slovenia 5 (20%), Austria 5 (20%), Italy 6 (24%), Croatia 9 (36%), undergraduate students. During the course, each team had an academic coach who acted as a facilitator for the team and gave instructions on the ideation process and the use of storyboards. The study was conducted after the project.

4.2. Guidelines for storyboards

Before the study, the students were given guidelines and tips for creating storyboards. Assisting framework for defining the storyboard scenarios included four reference questions. Students needed to think of who the users are (demographics), what they use (product), where they use it (location), and when they use it (time and context). The tips for creating the scenes were presented in a few sentences (Figure 1).



Tips:

- Scenes can be described by sketches, pictures, text, arrows... use what you are most comfortable with
- Pick one combination of 4 variables from the previous slide (e.g. user: woman in her 30s, product: breakfast-eggs, bacon (think of the waste which will be left), location: kitchen in the house, time: morning, breakfast)
- For every scene (step) think of what the user might be feeling, what are his concerns – you can write it below the picture, as a „thinking cloud" or any other way → think of the requirements for the product which these concerns could imply

Figure 1. Instructions of storyboard creation (graphics source: Pinterest)

4.3. Procedure and questionnaire

Participants were introduced to storyboard method as a part of the lectures. Those who introduced storyboards in this project were Design methodology lecturers who were familiar with all the tools and methods in the product development curriculum. After the lectures, the student teams had to create storyboards to understand how the product would be used by the potential user persona. In the study, the students were asked to create a storyboard without using a specific storyboard template. They

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could choose the storyboard format and scenario representation to their liking. For example, they could use the images from the Internet or draw stories by themselves in frames. After creating the storyboards (2nd phase of the product development process), they were given a questionnaire. Questions consisted of checkboxes, with a scale 0-5 (0 - I have not used this method 1- not useful at all 2 - didn't have much use of it 3 - somewhat useful 4 - useful, 5- very useful), yes/no responses and open questions. There were following questions:

- Q1: How useful did you find each of the following methods (referring to Storyboards)? (scale 0-5)
- Q2: Did you manage to extract functional requirements from storyboards? (yes/no)
- Q3: Did storyboards help you with identifying user problems and concerns? (yes/no)
- Q4: Did you have any issues with creating the storyboards scenarios? (Identifying user behaviour, product usage, user habits identification etc.) Please write them. (open question)
- Q5: Do you think it would be easier to make storyboards individually or in a team? (individually/team)
- Q6: What did you use for storyboard representation? (Multiple choice checkbox: hand drawn sketches, sketches drawn on computer, images, diagrams)
- Q7: What was for you the biggest obstacle with creating storyboards? (user identification, representation - sketching, lack of ideas etc.) (Open question)

5. Results

The results of this research are divided into two parts. In the first part we see an example of two different types of storyboards and how the functional requirements can be extracted from them, while in the second part of this chapter we find the results of the questionnaire.

5.1. Storyboards created by students

Figure 2 shows an example of a text-based storyboard scenario created by students. They managed to extract the functional requirements from the text-based storyboard, as can be seen in Figure 3. The students imagined different activities of personas (fictional users) taking place in the context of kitchen waste disposal. For specific persona, each activity is described as one sentence and included the user's feelings and concerns while performing the described activity. Afterward, at least one functional requirement was defined from each user's action.

1. *The middle aged man*
   1.1. The plastic trash can is always full because his family produces a lot of plastic which occupies a lot of space.
   1.2. His kitchen disposition constrained him to put different trash cans in different spots, and he needs to go around the kitchen to get waste to the correct bin.
   1.3. He gets his hand dirty when removing the bag from the bin.
   1.4. He is bored about the need to go out and throw away the garbage.
2. *The kid*
   2.1. The kid wish to do recycling with food residual and paper but he has just one bin and so he decides to throw everything in that bin.
3. *The disabled*
   3.1. The disabled has difficulty in folding the pizza box in order to fit it in the paper trash can.
   3.2. This person's humid is very smelly.
   3.3. He finds difficult moving to different trash cans.

Figure 2. Text-based storyboards for different personas

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1. *The middle aged man*
    1.1. Plastic compression
    1.2. Other waste compression (humid etc.)
    1.3. The product should permit the user to throw every kind of waste in the same spot
    1.4. Automatic open and closure of the bin
    1.5. The garbage bag once full should be closed automatically (or at least help the user doing that)
2. *The kid*
    2.1. The product have to help sorting out the trash.
    2.2. It may even sort it in a full automatic way by itself.
3. *The disabled*
    3.1. Compressing (or help to) big waste items as the pizza box.
    3.2. Smell removal from the humid

Figure 3. List of extracted functional requirements for the storyboards from Figure 2

Another approach to storyboard representation is the image-based storyboards, as shown in an example on the Figure 4. That type of storyboards can be created by using hand-drawn sketches on paper or on the computer, or using the existing images from the internet and other sources. From the participants' reports it was shown that the image-based storyboards can also be used to identify the functional requirements for a new product. Creating multiple storyboards for diverse users and situations enables the students to generate a wider list of potential functional requirements, which address different user concerns in various situations (Figure 5).

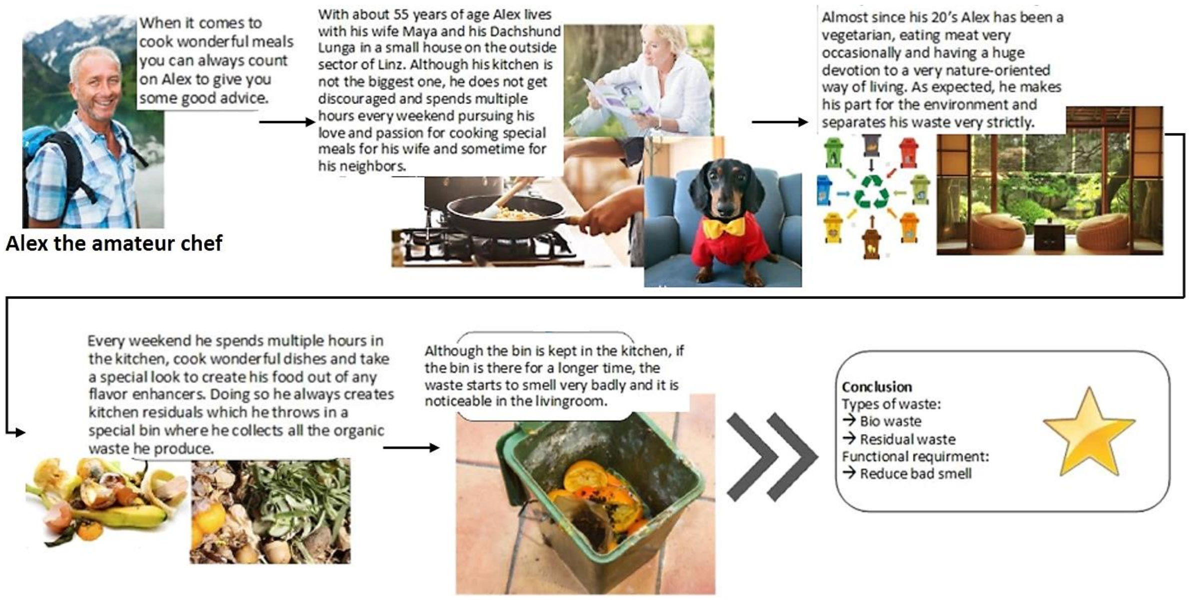

Figure 4. Image-based storyboard example for one persona

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Functional requirements

- Integration into furniture;
- Reusing medium from other appliances to clean food packaging;
- Advanced connectivity (more e-assistant);
- Opening of the inlet without physical interaction of the user;
- Mechanism for reducing the volume of the waste;
- Possibility to store different types of waste (paper, plastic, organic and residual waste);
- Mechanism for reducing or prevent the bad smell from the organic waste container;
- Notification system for user regarding filling level of the container and increases awareness;
- No possibility of waste to get stuck on the container's inner walls;
- Easy and clean way of emptying the containers;
- Long lasting and energy saving;
- Eliminate or isolate hazardous functions from the user;
- Possibility of composting in a special container the organic waste;
- Need of an extra power plug;
- Possibility to store liquid waste;

Figure 5. List of requirements extracted from several storyboards created by one team

5.2. Responses from the questionnaire

The analysis of the survey results shows how the students perceived the storyboard method and also reveals some issues that students encountered with storyboards usage, which gives us some guidelines for the future development of the methodology for elaboration of functional requirements based on the storyboards. The summary of participants' responses is given below.

5.2.1. Q1: How useful did you find each of the following methods (referring to Storyboards method)?

- General perception of the students was that the storyboards can be useful. Namely, 70.8% found the storyboards useful, while 12% did not. 16.7% of participants could not decide whether storyboards were useful or not (Figure 6).

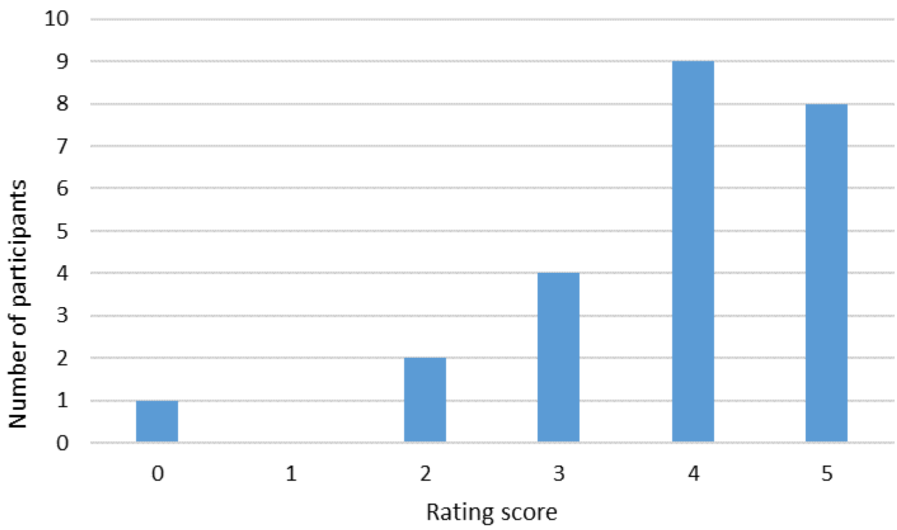

Figure 6. Ratings about Storyboards usefulness from 0 (not useful)-5 (very useful)

5.2.2. Q2: Did you manage to extract functional requirements out of storyboards?

- 88% of the participants managed to extract the functional requirements from storyboards, while 12% did not.

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5.2.3. Q3: Did storyboards help you with identifying user problems and concerns?

- The majority of participants (92%) responded that storyboards helped them identify user problems and concerns, while 8% did not find this method helpful in this regard.

5.2.4. Q4: Did you have any issues with creating storyboard scenarios? (Identifying user behaviour, product usage, user habits identification etc.) Please write them?

- 2 participants reported having issues with identifying distinct customer segments, whereas 3 participants wrote they had difficulties identifying user behaviours and actions for user personas they were not familiar with. 1 participant stated he made the storyboards based on his experience. 1 participant reported having issues describing the product usage.

5.2.5. Q5: Do you think it would be easier to make storyboards individually or in a team?

- Majority of participants find it easier to create storyboards individually (64%), while 36% would prefer to create them as a team.

5.2.6. Q6: What did you use for storyboard representation?

- The results are shown on Figure 7: Most of the participants have used images (60,9%) and hand drawn sketches (39,1%) for storyboard representation. Fewer used sketches drawn on a computer (30,4%), diagrams and flowcharts (21,7%) and textual description of the situations (8,6%).

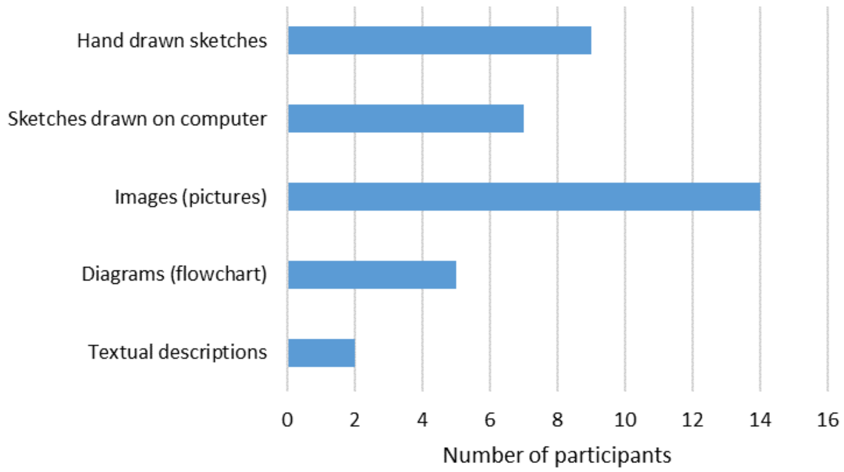

Figure 7. Presentation techniques chosen for storyboards

5.2.7. Q7: What was for you the biggest obstacle with creating storyboards? (user identification, representation - sketching, lack of ideas etc.)?

- The students listed a variety of issues which were grouped into five categories. Identifying user groups and typical behaviours was mentioned 7 times, representation, and visualization 4 times, describing unfamiliar user's interactions with the product 2 times, lack of ideas and creativity 2 times, and thinking of a plausible situation and teamwork were mentioned once.

6. Discussion and conclusion

In this paper, we presented the potential of the storyboard method for capturing technical requirements based on everyday scenarios of potential users. Our goal was to explore how to shift the focus of engineering students in NPD courses from engineering problems to user needs. Engineers mainly focus on how to ensure the functionality of the product and neglect the aspect of how a certain function of the future product meets the real needs of the user. Therefore, we integrated the method of storyboarding in the early stage of product development.

Interestingly, more participants preferred to create storyboards individually than as a team. There are several factors that may have influenced this study outcome. First, searching and processing information in a team has an additional level of information sharing, compared to individual work (Langfred et. al. 2014, Harms et al. 2017). Further, the students worked in virtual teams and had to communicate using technology instead of face-to-face. Lack of physical interaction results with decreased conceptual understanding of a problem (Kankanhalli et al. 2006). Students also had to use various technologies to communicate their ideas to teammates and collaboratively create a visual representation of the storyboard. Lack of experience and training in using the tools may also have influenced the results (Cordes et al. 2016). Since the storyboard method is predominantly a visual tool, it is not surprising that most students used pictures and hand-drawn or computer-drawn sketches and flowcharts, rather than the textual descriptions of the situation to create storyboards. Mechanical engineers are usually less confident with sketching (Wetzel, 2015), therefore the use of images from the internet helped them to better develop their ideas, without focusing on the sketching skills. However, some students had difficulty representing their ideas visually. As a result, some students combined customer journeys, personas, and storyboards into one visual or even fully textual presentation. Lastly, the most common issue for students was identifying the user groups and user's typical behaviours. This aspect of the storyboard method could be supplemented with other methods, such as market research and market segmentation, which would provide students with more detailed information of the potential users. Storyboards have an exploratory purpose and can aid the product understanding while also facilitating new idea generation, hence they can be used to stimulate the student creativity.

The results indicate that storyboards are an adequate method for identifying functional requirements. Further research should investigate the application of storyboards to another project task to validate the usability of the method; as well as its application in the final stages of the design process, for concept verification and testing the usability of the product. In addition, it would be interesting to investigate whether students from other disciplines, such as industrial design, would use similar approaches and achieve comparable results to mechanical engineering students."

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