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A SYSTEMS APPROACH IN TEACHING PRODUCT DESIGN

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ABSTRACT
In numerous cases, design professionals, engineers and marketers have tried attempting to clearly define and distinguish products from systems by questioning the differences between them within the context of design. Is a system a large and complicated phenomenon supported by a selection of single entity products? Are there sub-systems to consider in-between the product and the system? What about the components of a single entity product, is therefore the product not the system of its components?
According to Forlezzi, there are three models of experience: product-centred, user-centred, and interaction-centred, and possibly a fourth: system-centred [1]. From an engineering perspective, much has been written on Product Architecture, Platform Design, Modularisation, Product Structuring, etc. [2, 3]. In this paper, a human-centered approach towards systems and product design will be discussed in conjunction with studio teaching.

Keywords: Systems Design, Human Centeredness, Sub-system and Product Design, Industrial Collaboration

1 INTRODUCTION
In a fast-moving and complex economy, companies are constantly seeking competitive advantage through the development of innovative products, services and systems. The creation of "single entity" products, based on aesthetic and technical performance, would no longer meet the needs for solving complex problems within an environment in which technologies are more advanced and complex, as well as user needs more diverse.
Much has been debated on how to direct design education to create value-add beyond 'Core Industrial Design'. This value-add is to be established through focusing on 'Systems Design'.
At the Norwegian University of Science and Technology (NTNU) Department of Product Design, an educational framework for strategic design has been developed, where under-graduate (year 2) Industrial Design students interact and collaborate with a single company or institution to develop a wide variety of design concepts.
The uniqueness of this studio program is based on a systems design approach as a generator of design proposals, rather than the allocation of specific design briefs. The problem space had to be formulated and solved through a systems design process complemented with classical design methods. From an educational perspective, this led to intensive course preparation, student evaluation, as well as individual and group mentoring.

2 PRESENT STATE OF PRODUCT DEVELOPMENT STRATEGIES AND METHODOLOGIES
Product development is an important factor in technology-based firms. Achievements in product development determine the mid, and long-term viability of companies and economies[4, 5]. The process is complex because of the range of technical issues that must be considered, and variety of people and organizational structures that must be deployed over the product development life-cycle [6, 7]. Until now, a more direct applicable methodology to support systems design has not been developed yet.
Within the context of Systems Engineering (SE), there was an increased interest in designing the 'user experience' [8]. The SE "cradle-to-grave" structure and systematic approach was based upon the triumvirate of requirements, compliance, and reliability engineering. From a human-centered

perspective, it was first applied to the micro-ergonomic range of hardware design/engineering, software development, human factors engineering, and seller/purchaser economics, but later extended to macro-ergonomic endeavors, when it was appropriate to effect organizational change [9, 10]. This was emphasized from a lifecycle viewpoint, where the determination and analysis of the organization's needs and wants put the consideration of ergonomic criteria as early as possible [11].

The interest in designing experiences can also be seen as an initiative to enlarge the design space, as well as a development of design discourse 'beyond the object', and a response to the shortcomings of existing models of how usage and users are considered in the design process [12, 13, 14]. Methodologies were used to facilitate the generation of ideas and concepts systematically through specific creative and problem solving techniques, such as Morphological Chart Method, Objective Tree Method, etc. [15]

However, most of these studies were approached from a product engineering viewpoint. For example, several design methods were introduced to develop quantified structural variations based on functional surfaces and form factors [16].

Case studies addressing cost reduction and time saving, showed that predictive and creative product architecture-based DFA techniques were applied to accelerate the rate of product improvement as well as enhance product flexibility, which is affected by physical parameters, modules and the way these modules are designed in the product. [17, 18].

Literature related to strategic product design and development addressed consumer behaviour and their needs rather than the difficulties encountered in the use of such products [19, 20, 21]. For example, in New Product Development (NPD), a company only focuses on the entire process from market / company analysis and goal finding, through idea generation and conceptualization to the successful marketing of a new product.

3 INNOVATION THOUGH SYSTEMS THINKING AND USER-CENTEREDNESS

The introduction of Product Service System (PSS) shifted business focus from designing physical products to designing a system of products and services, which became more and more recognised as an important innovation strategy [22]. This approach towards innovation and product management was based on a new interpretation of the concept of '*product*', underlining that the client does not really require the products or services, but what these products and services help the user to achieve [23, 24, 25]. The emphasis on 'Service' as a form of 'Product' argues for the implementation of systems thinking in Design. At its broadest level, systems thinking encompass a large and fairly amorphous body of methods, tools and principles, all oriented towards the interrelatedness of forces, seeing them as apart of a common process [26].

The PSS model is also attractive from a business perspective, as it introduces new types of stakeholder relationships and/or partnerships, new constructions of mutual economic interests, and optimization of resources [27]. Within the above context, the designer is required to synthesise solutions emerging from the comparison of different viewpoint, needs and socio-cultural models, iterating from the traditional design domain to the domain of design management, and vice-versa [28].

From a methodological angle, it may be useful to develop system models of the product design process from a human-centred perspective by involving potential users in the initial stages. The understanding of user's technological and cultural frames, as well as behaviour in relation to material and immaterial aspects of service are very closely related to design [29, 30]. This is in line with the objectives of Macro-ergonomics, which constitutes research, development and application of organization/machine interface technology [31]. Within a fully harmonized work system, this "third generation" of ergonomics attempts to achieve major performance instead of the traditional incremental improvement, offering a complete systems thinking perspective through its own methods and tools. From a design perspective, macro-ergonomics can be useful to establish systems thinking in defining the overarching design problem and scenarios to achieve a significant value-add in the design solution [32]. It is to be researched if a systems approach in Industrial Design can enlarge the design space, through integrating PPS thinking and User-centred Design principles at a macro-ergonomic level.

4 SYSTEMS THINKING AND DEVELOPMENT AT NTNU DEPARTMENT OF PRODUCT DESIGN

The most inclusive definition of a *'System'* is a set of interconnected entities, comprising people, processes and technologies, which are dynamic in their behaviour and have a purpose or reason for existence [33]. From a system level engineering design approach, complex systems include large products, such as automobiles and airplanes, which comprise of many interacting subsystems and components [34]. However, in NTNU's context of systems design, students are expected to approach the problem using an increasing number of parallel lines of thought [35]. Those who have a an aptitude to process information and think holistically find it easier to structurally develop the system inclusive of its elements, boundaries and connections, compared to those who prefer to process information in parts independently and sequentially.

In the spring semester of 2004/2005 academic year, systems thinking was introduced in the undergraduate Industrial Design studio, based on a collaborative project with the Norwegian Postal Service (NPS). Reference to the metaphor *Mail Transporter*, holistic systems were analysed and proposed to improve the logistics of mail distribution [36]. In the same period of 2005/2006 a collaborative studio was undertaken with Porsgrund Porselaensfabrikk on the metaphorical theme: "Integrated Cuisine", whereas in 2006/2007 Laerdal Medical was selected as a collaborator to work with on the theme 'Life Saviour'.

The above projects stressed on the development of ergonomic work systems where students, in groups of 4, had to describe, formulate, conceptualise and finally materialise a product or sub-system, subordinate to a cooperative system. The interaction between user functions, marketability and aesthetics were emphasized, whereas technological aspects were superficially considered. This resulted in complete product-service arrangements prior to the actual design of its supporting sub-systems and products, which were conceptualised up to the level of design detailing.

In the case of NPS, selected designs were pursued for further refinement and materialisation beyond the studio environment. Collaborative work with Porsgrund did not lead to the continuation and realisation of selected design proposals, whereas the present collaboration with Laerdal is still in an early stage that it is difficult to determine what would be the outcome for further development.

Reasons for the difference in terms of systems thinking support, between NPS and Porsgrund, is that work processes of the former is based on a underlying logistic framework, whereas the latter misses the inherent culture to approach development of kitchenware from a multiple and sequential use perspective. NPS' logistic framework of mail production and distribution, made it easier for the students to develop 'improved' systems, which are within the scope of understanding and acceptance of NPS personnel. In the collaboration with Laerdal, the project was initiated from an existing product for emergency training, the'Vital Sim' system. In the discussion and preparation stage, prior to the commencement of the studio, a minor confusion arose whether systems design and development should focus on training or real-life patient treatment. Laerdal's interest in this project was mainly to improve the present training situation based on their existing 'Vital Sim' system, whereas NTNU aimed at a diversity of design proposals by emphasising on realistic scenarios in specific contexts. Finally an agreement was made by focussing on improving the training situation in specific real-life contexts, centralised around the instructor as the main user.

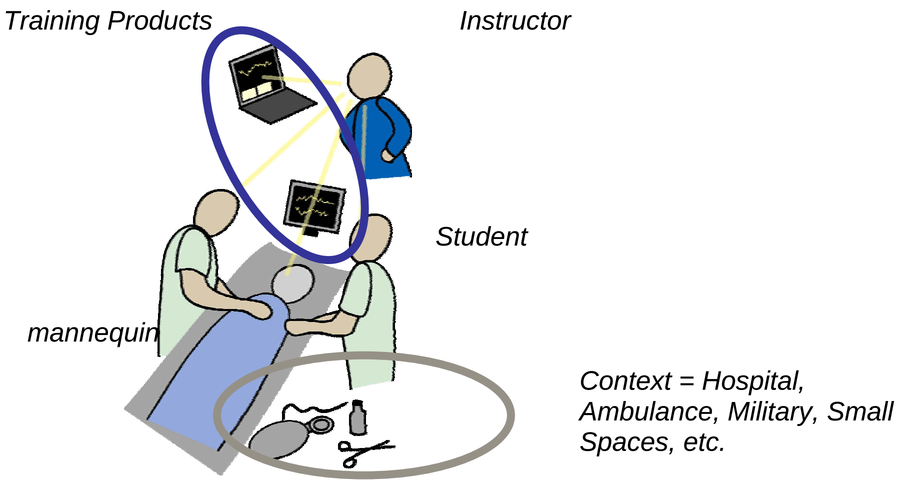


Figure 1. A general system's example on how to improve the training situation in specific real-life contexts, centralized around the instructor as the main user.

Figure 2. According to the context, existing training products may need to be substituted and complementary solutions introduced.

4.1 Mail Transporter: Collaborative studio with the Norwegian Postal Service

In the Norwegian Postal Service (NPS) project, it was obvious that systems design exposed students to complex design thinking at an early stage of their education. From a design teaching perspective, it was a challenging task to be clear and detailed in the organisation and management of studio teaching, as well as the supervision of students on how to plan and manage their projects. The terms 'system' and 'structure' were introduced in the project, whereby the system is the collection of sub-systems and products which make up the mail distribution service, and the structure is the pre-determined logistic framework on which this mail distribution system is based upon [37]. The term structure is diachronous in nature, which means that the relationships are time and sequence dependent.

In the first stage, student teams iteratively generated and evaluated several system alternatives through a series of scenario and task analyses. These alternatives were further elaborated into a feasible and detailed system concept. In 3 of the 4 system concepts a user-interface devices were introduced to manage the system structure.

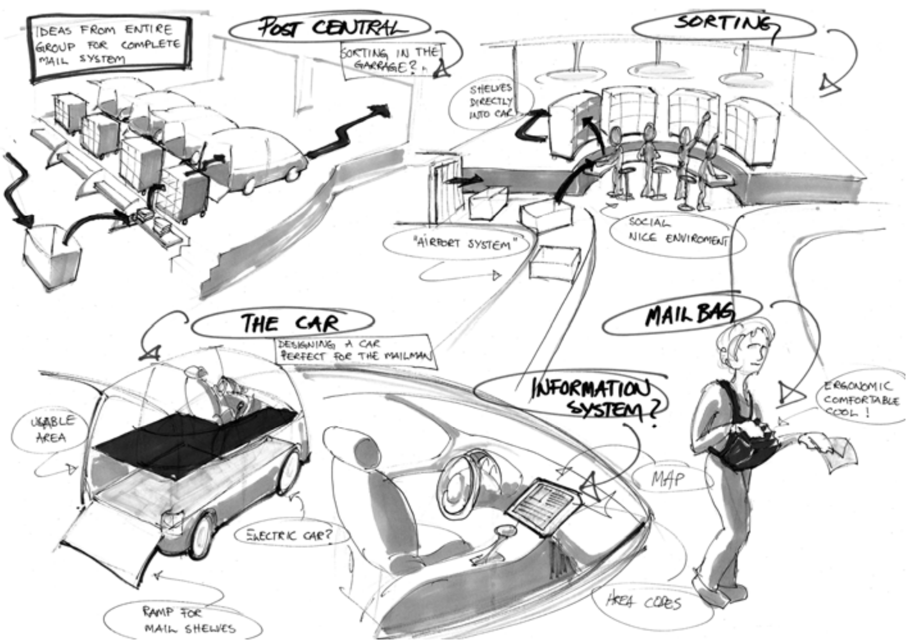


Figure 3. Example of a human-centered logistic approach in the development of a system idea for mail production and distribution, considering market and technological developments

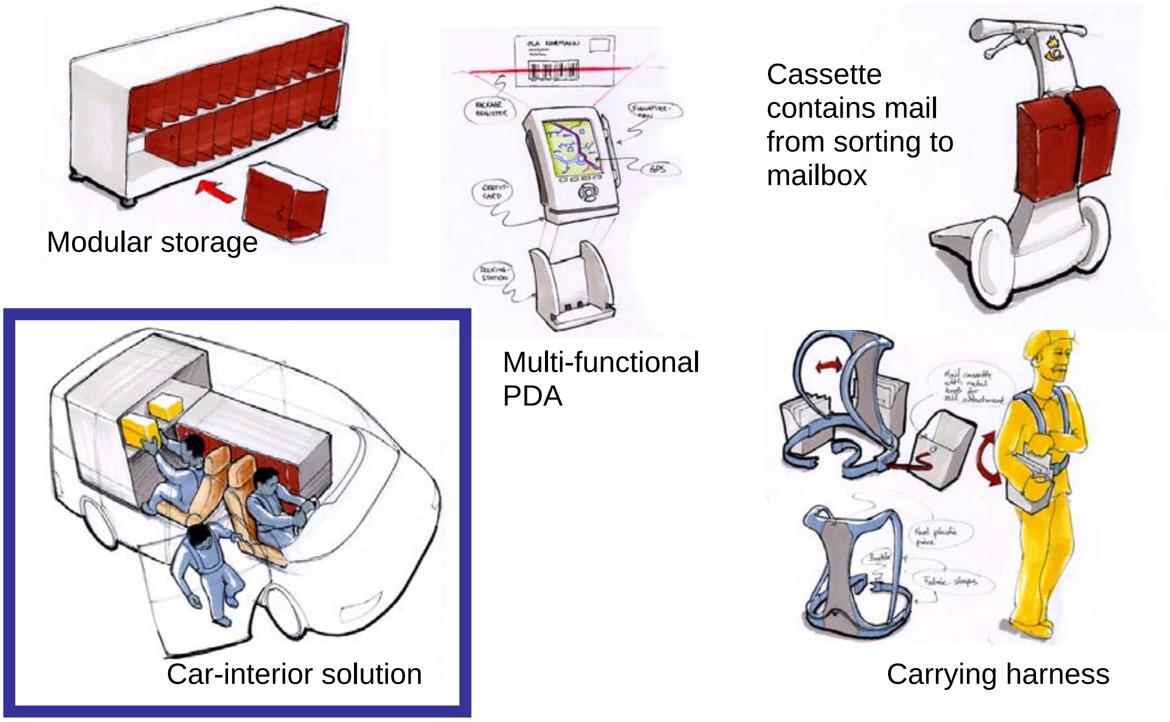
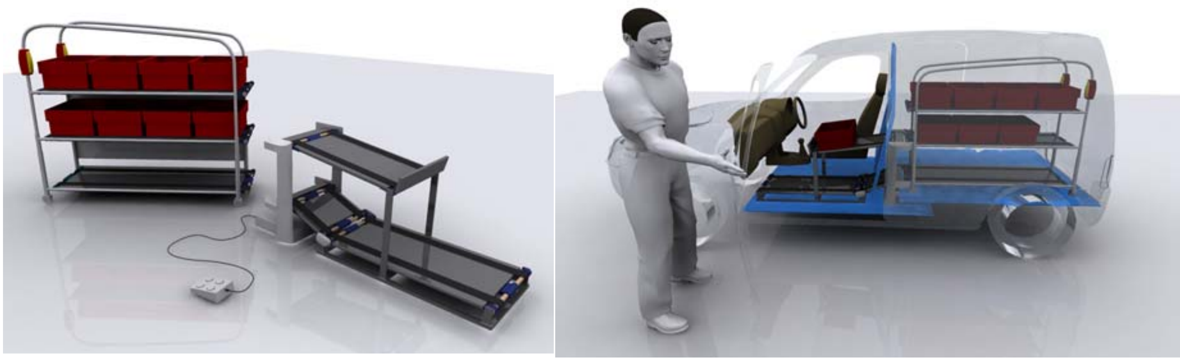


Figure 4. Example of the selected and refined system, based on a human-centered logistic approach in mail production and distribution.

In the second stage, subsystems and products were individually further developed into two or three detailed design concepts. The selected design concept was then subjected to iterative cycles of refinement, user testing and materialisation. The final stage was an extension of the studio, whereby selected designs were commissioned by NPS for further development and professional prototyping. The following figurers illustrate the process of system's development from systems concept generation to product design and detailing.



Figures 5A & 5B. Example of a detailed product design derived from the system in figure 4.

4.2 Integrated Cuisine: Collaborative studio with Porsgrund Porselænsfabrikk AS

Within the context of the metaphorical brief "Integrated Cuisine" and business scope of Porsgrund as a manufacturer of porcelain products, ranging from fireproof goods destined for professional kitchens, to exquisite, fine porcelain for the home, two directions have been identified for further exploration. These directions are: (1) Porsgrund Cuisine, covering areas, such as *Professional Kitchen, Hotel, Restaurant and Catering.* (2) Alternative Ways of Food Consumption

For 'Porsgrund Cuisine', the following aspects were considered in terms of functionality and application:

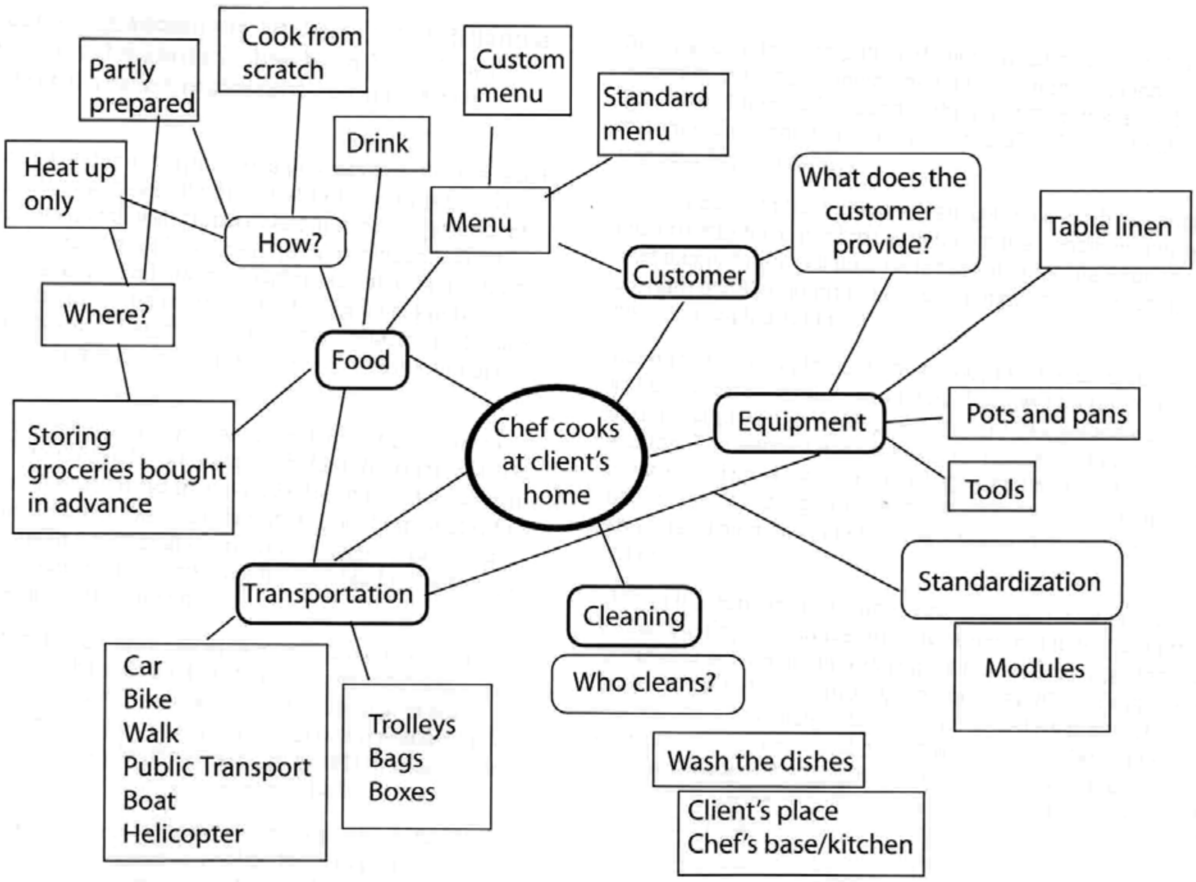
- Systems in relation to functional use of the professional kitchen
- Requirements and adjustments of porcelain products and ancillary utensils in connection to use within the professional market, such as standardisation, mass and rough handling, etc.,

- Use of products accommodated towards sizes of existing systems, such as dispensing units, buffets, ovens etc.,
- New trends in creative cooking
- Form giving and decoration in connection to small and large clients

Within the theme 'Alternative Ways of Food Consumption', the following directions have been suggested for systems development:

- Dining for Children
- Outdoor Food Consumption
- Fine Dining
- Fast Food Dining / Eating

The example below shows an iterative process of systems development, where techniques, such as mind-mapping and scenario-analysis have been applied to pre-determine the system. Within the theme of 'Alternative Ways of Food Consumption', the concept of 'Bringing the Restaurant Home', have been elaborated into a system.
Unlike the NPS project, the scope of exploration was broader, because Porsgrund did not predetermine an underlying framework. This has led to a more interesting and challenging task for the students, but difficulties were encountered in meeting Porsgrund's unspoken, more direct marketing objectives, which is mainly the selling of porcelain products.
Additionally, the system was also developed from a dimensional perspective, which meant that volumes and dimensions were more accurately predetermined and agreed upon, so that a physical fit of interacting sub-systems and products was made feasible.



Figures 6A & 6B. Mind map: 'Bringing the Restaurant Home'

Figure 7. Scenario development, which forms the basis for systems design

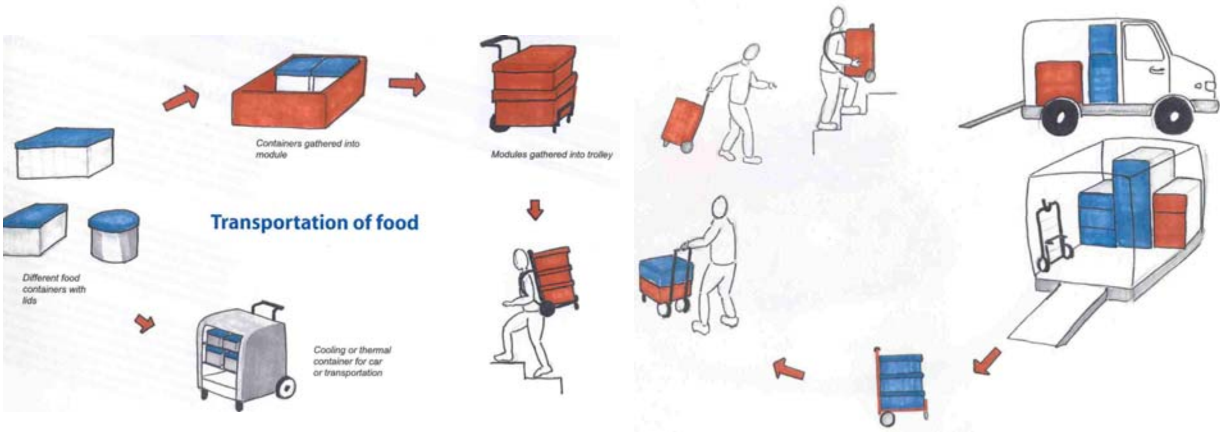
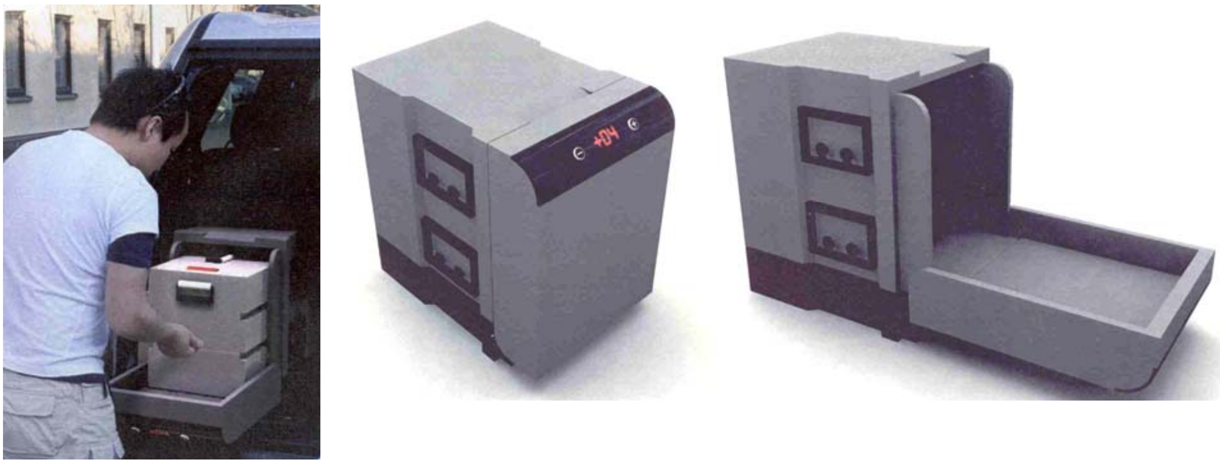


Figure 8. Systems design, where physical fit of interacting sub-systems and products was emphasized upon.

Figures 9A, 9B & 9C. Ergonomic and physical fit aspects were considered in the conceptualisation and detailing of the utensils carrier.



Figures 10A & 10B. Portable refrigerator also needs to fit alongside other equipment

4.3 Life Saviour: Collaborative Studio with Laerdal Medical AS

According to Laerdal, life saving Cardiopulmonary Resuscitation (CPR)**,** which is a combination of rescue breathing (mouth-to-mouth resuscitation) and chest compressions, is dependent on several coordinated factors, comprising of Therapy(guiding feedback during resuscitation), Training (guiding feedback during initial and maintenance training) and Evaluation (post event debriefing and periodic system statistics)

Within the framework of systems development, Q (Quality)-CPR Technology has been applied as a starting point to integrate both thinking concepts: “Circle of learning” and “Chain of Survival” [38]. By integrating these concepts, a holistic training approach towards emergency medicine from a user-centered perspective *(patient versus operator)* can be developed. However, the materialized outcome of the concepts in the form of a functioning systems design is dependent on scenarios, which is determined by environment and context. The following contexts were chosen as a starting point for group work in determining the system. Each of the five groups was allocated a context as listed below:

- In a emergency hospital setting
- In an emergency setting, where the ambulance play an important role from emergency site to operation room
- In a military setting: searching for and treating “wounded soldiers” in remote areas
- In small enclosed spaces or environments (e.g. narrow high-rise buildings, crowded street)
- In an independent living environment for elderly.

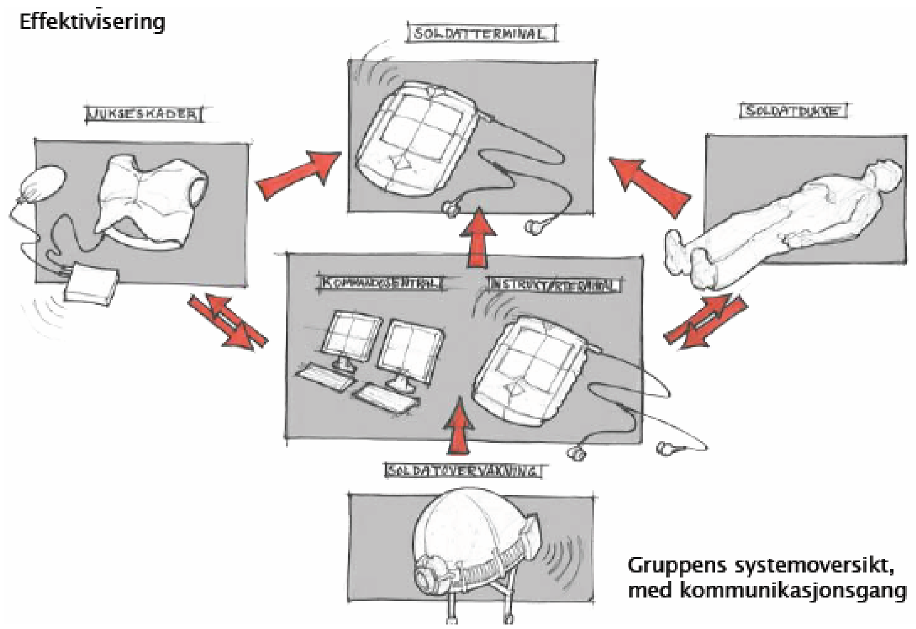


Figure 11. Systems development around CPR-training within the context of the miltary

5 IMPLICATIONS FOR TEACHING, LEARNING AND COLLABORATION

In all three systems design studios, metaphors were used to search for meaning and development of the overarching system. In the case of NPS, the intention of the metaphor to develop the problem space was limited by the pre-determined logistics of mail distribution, which to a certain extent structured and limited the variety of viable systems. In the collaborative studio with Porsgrund, students benefited from a metaphorical start in terms of systems thinking, but unfortunately the company was not able to exploit the design proposals, which resulted from this systems approach.

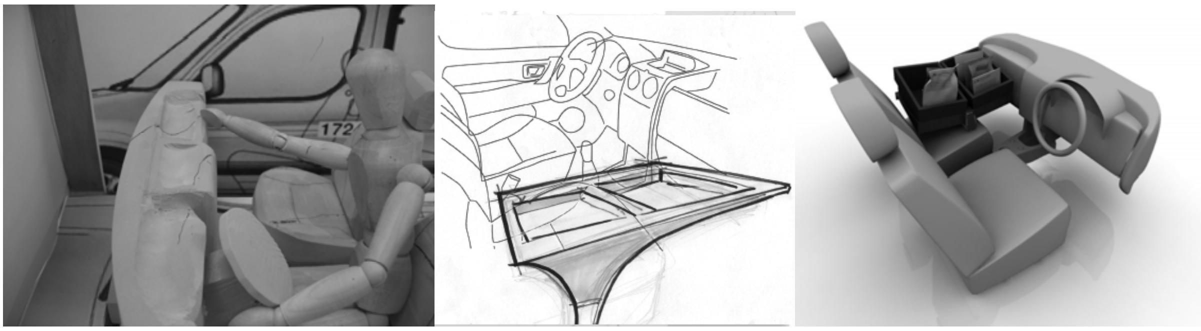
From a pedagogical viewpoint, students learned to reflect over and integrate methods and techniques within the framework of a systematic design process, as well as to understand an industrial setting by applying various methods of system analysis and design.

To apprehend current and to redesign new systems in the above context, students were guided to undertake observational studies, scenario and task analysis, systems concept development, etc. as a wide range of sequential and parallel activities. In the NPS and Porsgrund projects, the above activities uncovered critical issues in systems thinking and task allocation among group members on where to place the boundaries of the system. On one hand, the tighter the boundaries are placed within the system to define activities, the lesser the number of parameters and variables has to be considered explicitly, but the more the crucial interactions will be omitted or simplified. This may lead to errors or an unrealistic understanding of the user's situation. On the other hand, the further the boundaries are placed, the more complex are the set of variables and parameters to be considered, and the more work in systems thinking and management is required [39]. In the year 2 undergraduate studio, these novice design students experienced difficulties in combining broad boundaries with concrete consequence analysis. In such a teaching situation, stricter project management and customized supervision was needed to facilitate segmenting the system design process and allocating tasks.

In the collaborative project with Laerdal, early signs disclosed some difficulties among student groups in determining which sub-systems or products are relevant in building up a 'Training Systems' for emergency medicine rather than focussing on real-life patient treatment.

6 FURTHER DEVELOPMENTS AFTER COMPLETION OF STUDIO

The collaborative project with NPS has lead to four design proposals being selected further development and professional prototyping beyond the educational framework of studio teaching. One out of the four proposals was even brought further to series-production *(see figure 13C).*



Figures 12A, 12B & 13C. Analysis and concept development of a front-seat mail sorter

Figures 13A, 13B & 13C. Examples of user testing and detailing and prototype development

7 DISCUSSION

In the level 2 undergraduate studio project, the following results were found in the teaching of systems design to Industrial Design students:

- A systems approach proved to be an effective generator for developing a wide range of different product design projects within the specified holistic systems. This approach also provided students with real coordination and cooperation training alongside individual practice in a studio environment.
- Selected concepts and design solutions were further developed from functional models to working prototypes after the studio project was completed. The continued collaboration was beneficial for the students, as they experienced a real-life design and engineering setting beyond the classroom.
- It was a challenge to meet both objectives: pragmatic requirements of companies to generate specific solutions for product improvement, as well as educational objectives of the studio to aim for a diversity of innovative concepts.
- Fewer difficulties were experienced among students in defining the system's outer boundaries when the logistic structure of the human–centred system was partly determined by the nature of the project.
- In the transition from group to individual work students encountered more difficulties in determining intermediate boundaries and interface connectivity between the elements of the system, concerning overlapping scenarios and products. Additional tutoring in team and individual work, as well as in project planning was needed:
  - To understand at which level of systems thinking concepts had to be generated, suggesting the need for intermediate subsystem development prior to design concepts
  - To determine whether the boundaries for individual work needed to be determined by physical and dimensional aspects a product or user-scenarios and tasks, supported by overlapping products.

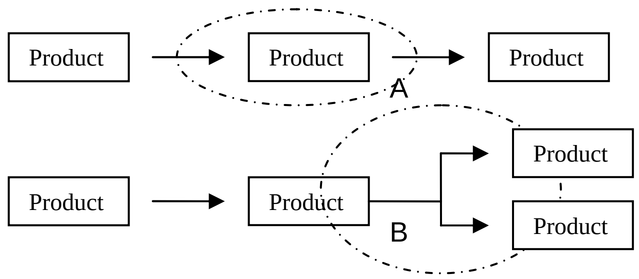


Figure 13. Situation A, clearly defined the design assignment within the system in the form of a product, whereas in situation B difficulties may occur, because the design assignment is based around an activity with overlapping products

- The natural introduction of an information hub within each system in the form of an *'Organiser'* such as a Personal Digital Assistant (PDA), highlights new challenges in design education, shifting understanding and teaching of systems design from a physical to an information level by incorporating elements of human computer interaction and information systems architecture.

8 CONCLUSION

In the NPS, Porsgrund and Lærdal collaborative project, it was obvious that systems design exposed students to complex design thinking at an early stage of their education. It was a challenging task to be clear and detailed in the organisation and management of studio teaching, in meeting the company's requirements, as well as in tutoring students on how to plan and manage their projects.

The three collaborative projects have demonstrated that a systems design approach encourages students to think broader and more in depth of the overall problem field. This has also been facilitated on how the assignment was formulated at a metaphorical level. Results have shown that interesting concepts were generated at a product level, but still connected to the over compassing system.

This approach of studio teaching has found support from the collaborators, because holistic systems thinking in groups, has lead to valuable innovative user-oriented strategic concepts, which the company has no time to explore.

Products and design concepts resulting from the systems has been varied and led in selected cases to further development and materialisation of an innovative product.
Bringing the design beyond the studio has also proven to be beneficial for the respective students' career as he or she is able to demonstrate that his or her design as been materialised in Industry.

Future research should focus on how to formalise a systems design methodology as a strategic tool for industrial design practice. Processes, which need to be carefully investigated, are:

- How to determine internal and external boundaries of and within the overall systems.
- How to meet expectations of the industrial collaborator, while not compromising on the educational objectives
- How to better facilitate and improve team and individual work among students, in relation to the creation of the overall system and its division into sub-systems and products.

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