Impact of engineering roles in a design process for solving complex problems

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INTRODUCTION

The last decades the world is changing at an even faster pace because of globalization, digitalisation, and the result of many recent innovations. The result of these rapid changes is an uncertain and unknown future. Universities have to make sure that what first year students need to learn, is still relevant after 5 years after graduating. Companies look for employees with both in-depth knowledge and skills that go beyond the current basic engineering skills. Solving complex problems for real-life challenges is necessary to make actual impact in the society. Complex problem solving requires interdisciplinary collaboration with multiple stakeholders and is challenging with only technicians with a monodisciplinary focus [1].

Future employees require creativity, organisational skills, international orientation and an entrepreneurial mind-set. This entails a different type of engineer, skill-set and a new

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engineering vision. A Think Tank has been setup to explore the future education vision of the Delft University of Technology [2]. One of the main findings were four new engineering roles with specific knowledge and skills to withstand the rapid changes and to solve complex problems. Each role has their own specific skill-set, language, problem approach and a description of their purpose and drivers within a company or academia context. For a short impression of the proposed engineering roles see table 1 or click on this link for the extended online version in booklet format.

Table 1. Short impression of the four proposed engineering roles

Engineering role	*Explanation*	*Heuristic question*
Specialist	The engineer who does fundamental research into a particular topic needed to contribute to the project.	How can we advance and optimize technology for innovations and better performance using scientific knowledge?
System Integrator	The engineer who brings components and people together to realise bigger integrated systems.	How can we bring together disciplines, products or subsystems into a functioning for a complete solution?
Front-end Innovator	Bridging the gap between user, user needs and adaptive design for projects.	How can we advance and apply knowledge and use technology to develop new products for the benefit of people?
Contextual Engineer	Exploring and preparing the environment, while taking into account the cultural, legal, ethical issues for implementation of the technological solution in society.	How can we develop and implement technology safely, ethically and internationally in society and industry?

After the development of these engineering roles, it is unclear how these roles can be used in education and the impact on complex problem solving. This paper presents the results of five experiments that have been developed and evaluated via a design-based approach. During the experiments the engineering roles were used to solve complex problems via an interdisciplinary team-based design thinking process. The focus of this research was on the experience of the roles within the different design activities, recognition of the roles and the relevance of the roles in education and work environment. This paper gives the first insights for teachers using the engineering roles within their own curriculum that include a project-based setup.

1 THEORETICAL BACKGROUND

Complex problem solving can be achieved via design thinking processes. This process is known for its effective experimental approach that addresses human-centred problems consisting of many unknown and little objective data [3]. It shifts the perspective from “designing products” to create “ideas that better meet users’ needs” [4]. Brown [4] describes the design thinking approach in three different stages inspiration (stakeholder collaboration in identifying problems), ideation (brainstorming, primary prototyping e.g. sketching onto paper) and implementation (creating a workable prototype for testing). Stanford d.school widely uses design thinking to stimulate radical collaboration for real-world projects to solve complex problems from any field. They translated the design thinking stages from Brown into five steps: emphasize, define, ideate, prototype and test [5]. The iterative cycles within the process and the experimental characteristics makes design thinking a good method to explore complex problems in a fast pace. During each process step different predetermined activities foster design thinking.

Depending on the process step and design activities two additional thinking processes are stimulated namely; diverging and converging [6] (Fig. 1.). Divergent thinking is important as it can explore and extend the problem and solution space in the process. It is the ability to extend the data collection to a particular problem or to explore concepts for possible solutions. Convergent thinking deals with revealing the facts based on the known knowledge of the concepts. It supports the decision process and focus on specific problems and solutions.

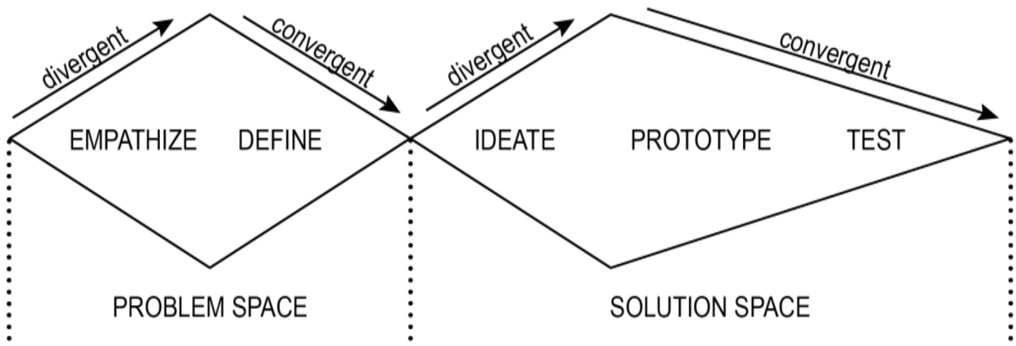

Fig. 1. Design thinking process including divergence, convergence and the problem and solution space

One of the design activities that enhances convergent thinking and increasing creativity is synectics. Synectics is a theory for the conscious use of the preconscious psychological mechanisms present in a person's creative activity [7]. It allows moving away from the original problem via an “analogy” and using “forced fit” to develop original solutions. Forcing to use the analogy as a stimulus can generate other ideas or solutions.

2 RESEARCH SETUP

The theoretical background has resulted in the development of design experiments using design thinking activities with engineering roles as synectic stimulus to evaluate the engineering roles. So-called “pressure cooker workshops” have been developed to execute the design thinking process in a fast-pace format. Pressure cooker workshops have been used in the field by (SME) companies to stimulate innovation and product development activities [8].

Participants of these workshops go through each design thinking process step under time pressure of around 3-6 hours. The time pressure encourages attentiveness, focus and creativity once creating a professional atmosphere as if the participants are on a mission [9]. With the support of proper facilitation it is possible to finish a complete design thinking cycle without the need to master design thinking skills. During this experiential learning process participants learn about the process, engineering roles as well as the content of the complex problem [10].

From 2016 – 2018 in total five pressure cooker workshops have been successively co-created with teachers. They were responsible for courses or projects that deals with real-life complex problems within an interdisciplinary setting. Each workshop consisted of the design thinking structure with each altered design activities depending on the course goal.

Within each workshop participants worked on a real-life problem in teams of a minimum of four participants interacting in four different engineering roles. Before the workshop started all participants had to fill in a questionnaire to determine their personal engineering roles. An example of a workshop and the activities can be seen in table 2. The design activities have been structured on a large worksheet and have clear instructions which is necessary to complete a design cycle within a pressure cooker workshop. The worksheet gave a professional and structured feeling for the workshop.

Table 2. Example of a workshop process

Course description:	"Interdisciplinary honours class next generation robotics. Robotics is a multi- and interdisciplinary engineering domain. The creation of innovative robots needs high level research in all disciplines involved. It is a "mission" in which top level engineers of these disciplines work closely together. Currently the TU Delft does not offer bachelor programmes with this "mission" scope. It is expected that industry will need more and more these broadly educated and mission driven engineers."	
Workshop goals:	This workshop is executed during the kick-off of the honours programme. During the workshops the participants go through a complete design thinking process to develop an alternative for a "reading mom volunteer" using robots. Participants are introduced to the engineering roles and are encourages to use these roles throughout the programme.	
Process step	**Goal**	**Activity**
Emphasize	Emphasizing in different target groups and their explore their concerns via interviewing the 3 stakeholders that are present at the workshop using each engineering role.	Empathy mapping [11]
Define	Formulate the most challenging problem for each engineering role including stakeholders.	Problem definition [12]
Ideate	Develop as many ideas as possible and translate the most inspiring idea from an engineering perspective.	Ideation [13]
Prototype	Integrate the ideas from the 4 engineering roles to one final concept and sketch the idea.	Minimum viable product [14]
Test	Present the concept towards the stakeholders and reflect on your defined problems.	Sketching

The five workshops have been evaluated via a design based approach [15] and the structure, materials and engineering roles were iterated on basis of the data collection: observations, field notes, open discussions and (open) questionnaires.

3 MAIN FINDINGS

The five workshops, topics and the amount of participants can be seen in table 3. The workshop results are discussed via description, supported by quotes and numerical results of workshop 3 and 5 (descriptive frequencies, Likert scale 1-5 strongly disagree to strongly agree).

Table 3. Workshop themes and participants

Ws	Theme	Participants	Year
1	Sustainability	13	2016
2	Robotics	12	2017

3	Building with Nature	25	2017
4	Communication and Education	11	2017
5	Building with Nature	26	2018
	Total:	*87*	

3.1 Understanding roles

The explanation of the roles was not clear and limited according to some participants at the start of the workshop or via the provided information. This problem has been encountered during the first workshops but improving the communication may not work for each participant. *“More detailed explanation needed in order to work with it” (participant 21, ws5).* Although 11 participants of ws5 agreed that the booklets provided a clear explanation of the engineering that the participants used during the design session. Furthermore, 11 participants of ws5 strongly disagreed to thoroughly prepare for the workshop. After ws5 only 1 participants did not agree to recognize herself in her own engineering role.

3.2 Added value

The roles were useful to generate ideas from a broader perspective in addition to their own disciplinary background. Particularly within the problem space of the design thinking process. The front-end innovator and the contextual engineering roles stimulated the emphasize phase even more. It enhanced the focus on human-centered design according to the participants: *“Normally I think more about how the products, in this case the robot, is done and don't really care about society will react to it.” (participant 11, ws2).* Three workshops (ws2, ws3 and ws5) involved access to stakeholders and end-users experiencing the real-life problem and this supported the steps in the problem space even more (Fig. 2.); *“You can define the technical problems you need to solve based on user experiences” (participant 1, ws2), “it is a good exercise to view problems or challenges from a certain perspective” (participant 2, ws1) and “the roles have an added value in analysing the problem from different perspectives” (participant 12, ws2).* Participants thought working from an engineering role is *“very useful because you are more conscious about your way of thinking; more organised” (participant 11, ws1).*

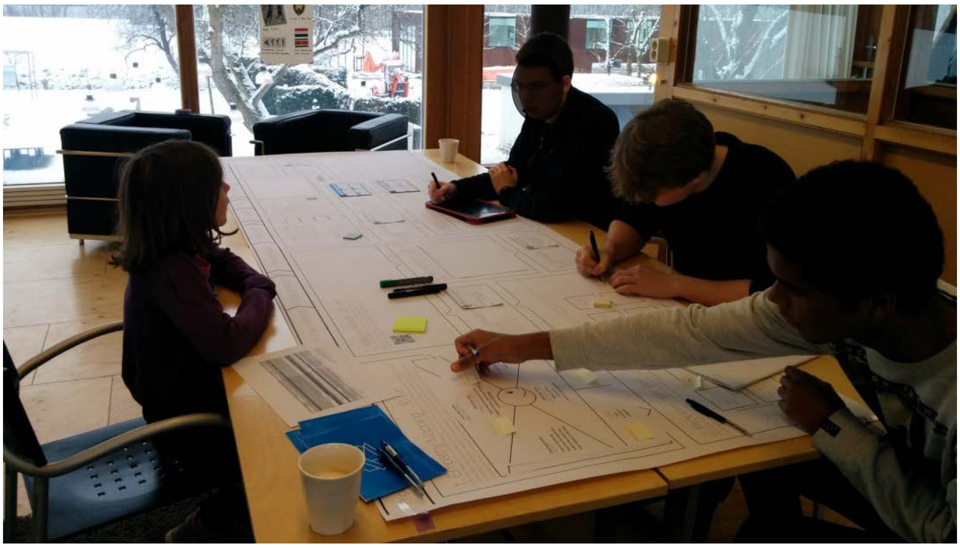

Fig 2. Interviewing end-user using empathy mapping (ws2)

During the idea generation step the different engineering roles are experienced very well; *“multiple views on the same subject are needed to come to a good product” (participant 2, ws2) and “seeing the opinion of people from other perspective while maintaining my own* *perspective made me think in a very different way" (participant 8, ws2).* However, we noticed during the discussions and from the content of the ideas that not every participant maintained in their specific role. One participant stated: *"there is lots of general discussion hence there is no need for a specific role" (participant 11, ws2).*

In total 12 participants agreed and 3 strongly agreed from ws5 that the engineering roles did result in more integrated solutions. The system integrators felt more responsible during the prototyping phase once all the ideas become one integrated concept; *"The point of view of an system integrator with respect to the whole system is important to bring everything and everyone together" (participant 2, ws2)* and *"there are still a lot of problems that arise when trying to combine different systems. A system integrator can constantly work on this" (participant 1, ws1).*

Testing the prototypes from an engineering perspective was *"experienced as more difficult from your own engineering role" (participant 6, ws2)*. Due to the pressure cooker format there was no extensive time to test the prototype via all four engineering roles. Reflecting the prototypes using the engineering roles during the presentation revealed that all engineering roles had a part in the solution.

3.3 Usability

Participants that were working from their personal engineering role experienced it as natural; *"I played the role that came out of the test I experience as something that felt natural"* (participant 3, ws2). However, "forcing" participants using only their assigned engineering role felt limiting and gave a compartmentalized experience. As stated before, some exercises were a better fit for specific engineering roles than others. During ws5 it was communicated that the participants were "responsible" for their assigned engineering role and could work from their personal or other engineering roles. Nonetheless, during ws5 8 participants agreed and 8 strongly agreed that working from the engineering role felt limiting.

3.4 Relevance

8 participants agreed and 12 strongly agreed from ws3 that the engineering roles were relevant for their disciplinary field. 10 participants agreed and 10 strongly agreed of w3 that the engineering roles were relevant for the building with nature session. Only 2 participants disagreed that the engineering roles were relevant for the technical working environment. The participants of ws5 were less positive compared to ws3. It was observed that it was difficult to enthuse them during the whole pressure cooker session.

4 DISCUSSION AND CONCLUSION

Experiencing the engineering roles within the pressure cooker workshops was challenging at first. It could be clarified due to the characteristics of our fast-paced pressure cooker workshop and the limited time we got to explain the engineering roles. After working with the engineering roles the participants got more acquainted with the roles. Improvement on communication and time management is necessary to tackle these problems.

Solving complex problems using a design thinking process can be enhanced using the engineering roles. It supports future engineers to make their natural role more explicit and to think outside their own technological discipline to develop social responsible solutions. The design process and the engineering roles stimulates interdisciplinary collaboration and results in more holistic and integrated solutions for real-life problems. Using the roles as an analogy synectics technique can extent the problem and solution space of the students during a design thinking process (Fig. 3.). However, it has not been proven that the roles extended the data collection in the divergence phase and supporting the selection process in great extent. As this is a design based research and the sample size is small, the effect has not been measured extensively and the questionnaires changed over time. Further research is necessary via an embedded case study.

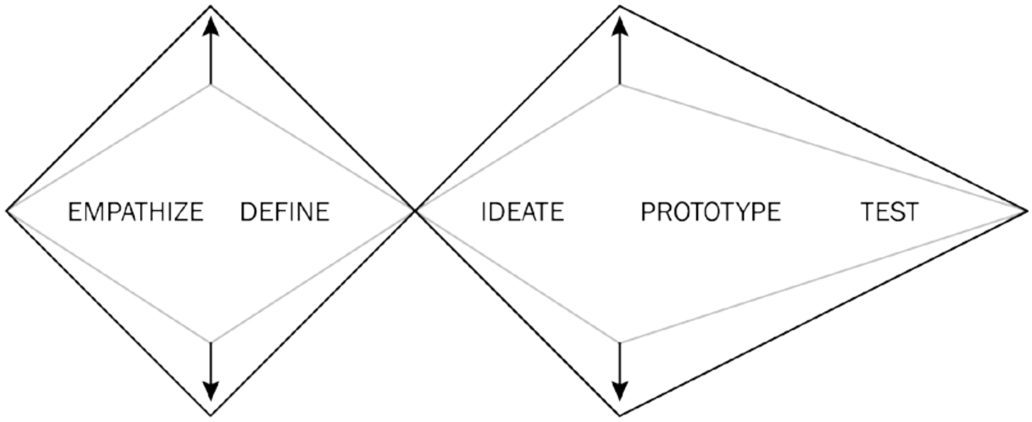

Fig 3. Extending the problem and solution space

The success of the solved complex problems using the engineering roles need to be evaluated in a real-life context. The 4TU.Centre for Engineering Education is currently developing an interdisciplinary course in collaboration with companies to examine the engineering roles solving real-life complex problems during a 10-week design thinking process.

5 RECOMMENDATIONS

If teachers would like to use the engineering roles during an experiential learning environment, such as a pressure cooker workshop, it is recommended that students prepare properly to become acquainted with the engineering roles. Communication about compartmentalization is key for a motivated mind-set to think and act from the engineering roles. It is important facilitating the students in the process reminding them using the engineering roles as analogy. Stimulating the students with engineering roles booklets and teacher facilitation might not be sufficient. Additional probes and (heuristic) questions need to be developed to improve the stimulus.

Specific engineering roles seem more beneficial in certain exercises or design thinking process steps. These steps could be enriched while enhancing the responsibility of the specific engineering role. Additional research is necessary to analyse which engineering roles are more beneficial in each process step.

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