A DESIGN-BASED VISION ON FUTURE ROLES IN ENGINEERING

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ABSTRACT

In this paper, we present a vision on how engineers can play different roles in future society 2030. First we predicted how society in the Netherlands (in relation to Europe and the rest of the world) is going to develop and how future engineers will behave, act and take their position in this future world. We used the 'Vision in Design' methodology to unravel the complexity of future society step-by-step and to understand the diversity of engineer(ing)-behaviour: 260 relevant future conditions for 2030 were derived from 10 interviews with visionaries in society, experts in the field of engineering education and from literature search. Clustering these factors into ten driving forces helped us to discover three independent determining dimensions, defining eight possible engineer-behaviours in 2030. As a result of this rich contextual research, these eight roles are further illustrated with accompanying skills and pathways to support role development. The vision and roles have been developed in co-creation and validated in a series of workshops with a wide variety of people within and beyond academia and within the professional world of engineering.

KEYWORD
Engineering education, Vision in Design, Engineering Roles, Higher Education, Behaviour, CDIO Standard 1 (Context)

INTRODUCTION

In 2015 a Think Tank was established at TU- Delft, facilitated by the 4TU Centre for Engineering Education (4TU CEE). The Think Tank's main aim was to discover what future engineers should learn during their education to be properly prepared for the future labour market in 2030 (Kamp & Klaassen, 2016). Three main outcomes resulted from this endeavour; **thematic interdisciplinary hubs** as a meeting ground for teachers, learners and researchers and engineering professionals on trending scientific developments besides the regular disciplines. **Building a common language** amongst engineering professionals with different disciplinary backgrounds. Last but certainly not least **different engineering roles** that create more personalised profiles on top of disciplinary knowledge. Engineering roles may serve to a) stimulate personal development of the engineer, b) facilitate teamwork and c) create multiple perspectives via engineering roles, which help to tackle complex problems by means of engineering and technology (Hooimeijer, et.al 2016, IGEM 2017).

The latter outcome on different engineering roles was widely supported and found its way in the TU Delft Vision on Education 2018- 2024. Follow up questions were concerned with, "How to scientifically substantiate these roles or any type of roles for education"? Why do we need roles and are the established roles "THE" roles to work with? And how should these roles be implemented in today's education? Therefore, we have continued this research and reframed the roles via the design engineering research method, called "Vision in Design". This reframing activity resulted in a vision of the future context, future roles engineers can play, possible educational concepts that relate to these roles and illustrations for possible implications of these new insights on higher education.

Thus, 4TU CEE decided to involve "Reframing Studio", a strategic design agency working both in the fields of future business development and future societal change, to:

a) re-explore the potential relevance of engineering roles in education;
b) create a vision on future education which allows for a more diversified approach to embedding engineering roles in Higher Engineering Education and;
c) create a more profound theory that would back up the use of engineering roles as a new route to differentiation in engineering education.

The method used to reframe the future of education and the possible roles engineers can have is called Vision in Product Design, developed in 1995 by Paul Hekkert and Matthijs van Dijk (2011). It is a method that allows for solutions **emerging from** the future, as opposed to **imposing** solutions for current problems, **onto** the future.

The reason 4TU CEE chose for Vision in Design as a viable method to explore the future of higher education is the fact that abduction is at the basis of pragmatic research. Pragmatic research helps to infer the likelihood of certain future developments and results. At the same time pragmatic research does not provide a conclusive direction, but allows for multiple and workable solution paths (Dorst, 2013). The Vision in Design method helps us to identify or design a process towards new meanings of education rather than framing the design solution as the one and only answer (Hekkert & Tromp, 2014). As van den Akker (1999) states; it realises a set of procedural design principles valid for a particular context domain. The outcomes are determined by the level of engagement within the context domain of education, technology and (applied) science.

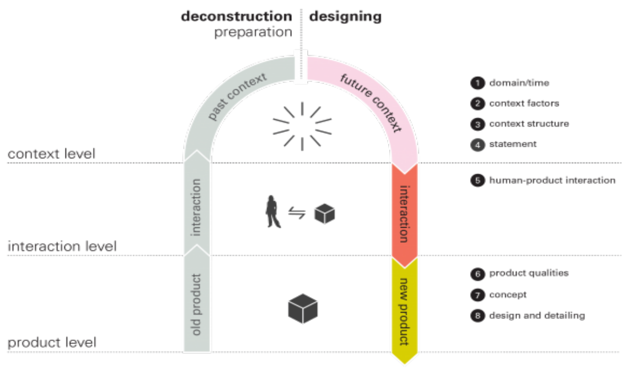

Fig. 1. Vision in Design Process

In Figure 1 above, we find a conceptual representation of the Vision in Design Process. It states that before we start to think about future possibilities we first need to deconstruct the current design for a particular solution. To understand 'the why' behind the 'world of solutions' currently used. It creates a sense of urgency for change and helps to start acting as a responsible organisation within the higher education domain.

Deconstruction

On the left-hand side of Figure 1 we find the deconstruction process. The deconstruction phase consists of 3 steps: understanding the artefact as such (the product level), the "what" , understanding the relationship between an end-use and the artefact (interaction level), the "how" and understanding the conditions that were taken into consideration (the context level), the "why". The deconstruction phase helps us to understand if current policies, services or products (the 'artefact) are still meaningful within the current context, the world of today.

A deconstruction phase is therefore not executed to only asses the current artefact as such, but also to understand how the artefact elicits specific effects on its end-user within the context it has been designed for. It unravels if the artefact elicits the desired effects of the end-user through the interaction and therefor is still of meaning within the current context. Often it is discovered this is not the case.

Designing

In the 2015 Think Tank we already found that a) we needed to educate an engineer as a whole person, who should be able to reach his/her full potential by acknowledging that personal development is part and parcel of education. b) This would require a more specific profile embedded in the current engineering programmes, including coherent tracks across the university and acceptable to accreditation bodies. Finally, it should create added value for future society.

The reframed and leading question for this consecutive research is: "What roles of the engineer could be of meaning in a future society?"

The Vision in Design method initially explores a future context (2030) related to a specific domain (in this case the domain of technology, education and society) by first collecting the building bricks, you could say the conditions, a future world is conceived of. These factors are distilled from interviews with key game changers in the field, literature research and reports that deal with the future of engineering education. All these different techniques lead to an understanding of which specific type of factors need to be taken into account. There are two time-dependent factors: the 'developments' (such as demographic changes over time) and 'trends' (behavioural change over time) and two time-independent ones, the 'principles' (laws of nature, such as the theories on emotional response) and states (cultural phenomena that are not in principle stable, but stable within the scope we are doing research for). Successively, each of these labelled factors are categorized by a design team into clusters, the driving forces of the future context. An underlying pattern existing out of three dimensions describe the relationships between all these ten driving forces and give direction to potential future roles engineers can have in the future world. Future dimensions thus typically define the design space from which the design solution should emerge.

In this study, we'll share the initial steps results in a vision for higher education and the validation of an initial design solution for Higher Education (Curricula.)

Educating future engineers

How can we equip future engineers with the skills they need to play their role?

In the beginning of this design research seven people in the Higher Education Field have been interviewed. These were researchers, policy makers of the Rathenau institute, TU Delft, M.I.T., Leiden University, Utrecht University, Institute for Social Research and Plant engineering and Design. Many more books on the future of Higher Education, Technological Developments have been consulted. Resulting in over 260 future context factors. Through a process of expert discussions and sorting, these were clustered into ten driving forces and reduced to a framework of three dimensions, leading to eight different roles an engineer can have within future society. A future engineer can also give expression to a combination of roles at one moment in time or shift roles depending on the situation or context encountered at a certain moment. This framework has been presented in several workshops, in which a total of 32 people attended to validate and discuss the framework as established. In the following paragraphs, we'll share a summary of the framework, the possible engineering roles and the validation results from the workshop.

Ten Driving Forces, Three Clusters in detail

The framework consists of three major dimensions: engagement with technology, trust and collaboration predicting the way engineers may interact with work, and development cycles (of products, systems, services, etc). Each of these dimensions is defined by the ten driving forces which have emerged from the 260 future context factors and will be described and visualised below.

1. Engineers will increasingly find purpose in salient societal challenges
2. Meritocratic engineering culture and education as 'rite de passage'
3. Science is no longer the only source of truth
4. Engineering talent will hop to and from new urban hubs
5. Meaning-making as the backbone for digital and analog growth
6. Technology will smooth out people's fear of technological change
7. The future engineer is intrigued by things, and by the people in them
8. People will have a life-long entrepreneurial mind-set
9. Collaboration will be more open, interdisciplinary and mediated by 'black-box' systems
10. 'Learning' will mean staying in tune with the next big things

Figure 2. Ten Driving Forces for Engineering Education

Engagement of future engineers in the quest for technological solutions are driven by societal **challenges**, like the grand engineering challenges or a deep desire to explore and contribute to the understanding of **technological phenomena**. Engineers will be faced with the fact that graduating as a "rite de passage" is opening doors to a future career and is necessary to grow. At the same time the results of scientific endeavours are no longer taken at face value and not necessarily accepted as a source for "the best" technological solution (driving forces, 1, 2, 3 and 7).

Trust and Collaboration is the second dimension showing the interaction at an **interpersonal** level stimulating small disruptive innovations at a level where systems do not yet exist. Opposite the interpersonal there is engagement with incremental (technological) improvement as part of building systems to ever better technological results. Technological hubs like Silicon Valley or increasingly Singapore and other Asian hotspots are bringing together innovative kick-starter's and front runners in tech (Aalto University, 2017). To be on the edge of technological development the engineer needs to go where tech is big and happening and have trust in interpersonal relationships. On the other hand, we are all part or will become a part of the **system** through permanent dataflow. Institutes and multinationals will drive for more systemic change and engage different types of engineers to master, alter and steer the dataflow systems. Although technological change is accelerating, it still needs a story. Meaning making as a part of trust and collaboration with the system or with individuals will still be at the centre stage for technological acceptance and in the domain of engineering education (driving forces 8, 4,5, 9).

Development Cycles are the last dimension driving the engineering and learning behaviour now and in the future. Development cycles are going **faster** all the time requiring swift entrepreneurial behaviour and forcing people to grasp every other opportunity. Moving on to the next big thing stimulates and pushes lifelong and very personalised learning for engineers in every walk of life. Contrary to the fast, we find **slow** development cycles. These process of long-term technological advances, which require long and dedicated attention to development, implementation and systems adaptation, taking into account governance, legal, policy issues and certainly cultural norms and values.

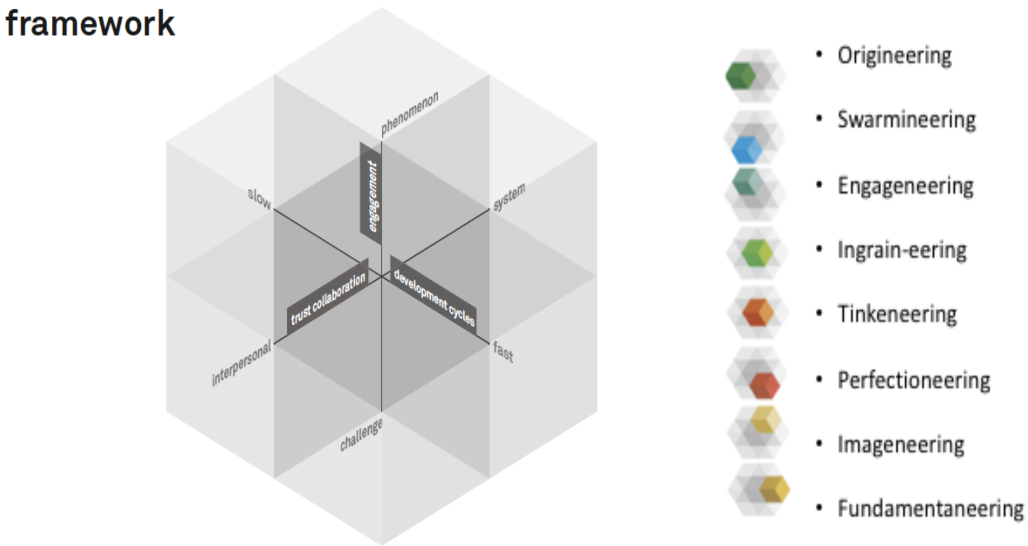

Figure 3. Framework for the Future of Engineering Education

The framework shows the three driving dimensions that are likely to determine engineering behaviour. At the end of each axis one finds the future determinants: Challenge versus Phenomenon, Interpersonal versus System, Fast versus Slow. Each combination of determinants give an insight in a possible role engineers can play in the future, i.e. in the future behaviour and underlying concerns of the engineer of the future. Each possible role can be addressed through the realisation of an educational path, and through specific life experiences along the way. The model frames the diversity of roles engineers can have, a diversity of roles that is appropriate within future society. The type of engagement with the future 'world' will determine the skills needed. Of course these roles will evolve over time with the ever-changing context taken into account. Some of the behaviours have already taken root in society. Others are yet to emerge and some are still to be detected. Each of these insights into future roles of engineers in society will be elaborately described in the forthcoming book and find their origins in the engineering profession.

Challenge x Interpersonal x Fast

1. origineering
Seizing a societal opportunity to bring people together or work together creating value and impact on the short-term

like a serial entrepreneur
skills/attributes: initiative and self-direction; courage: resilience; business sense/economic realism; the ability to apply theory in practice; market intelligence

Phenomenon x Interpersonal x Fast
5. tinkineering
Identifying with the 'state-of-the art' in several specific fields of interests and staying up-to-date through like-minded people with a similar strong interests. Finding ways to apply the latest insights/ discoveries/technologies in real-world settings;

like an amateur professional
skills/attributes: trend awareness; adaptability; self-direction; tech-savviness; practical ingenuity

Figure 4. Two examples of Engineering Roles

WORKSHOPS

The validation workshops questioned participants (n=32) from the engineering field and in academia on the following aspects:

- Resonance: Do you recognise these behaviours in your field of work and do you see these behaviours becoming more significant in your field (scored on a Likert scale 1 to 7 from low neutral to high.
- Assessment: at the end of each session participants were questioned on:
  - the relevance: of the frameworks for the field of engineering, (Likert scale 1-7, not at all relevant to extremely relevant
  - the appropriateness: Is it acceptable to use this framework on an ethical level. (Likert scale 1-7, not at all appropriate, to extremely appropriate)
  - The strategic value: can it be used as a tool for educational institutes for strategic planning (Likert scale 1-7, low value to high value)
  - The inspirational value: is the framework an inspiration to developing new educational systems (Likert scale 1-7, not at all inspirational to extremely inspirational)

  Questions were again scored on a scale from 1-7 and participants were invited to give comments.

Note that the questionnaire as such is not tested on reliability. The questionnaire was rather a departure point for discussion and not consistently scored. The sample groups are small and of diverse nature, not allowing for statistical violence. The scoring is therefore, reported as descriptive results and discussed for each group, including the summarised qualitative comments. Sometimes part of the ongoing discussions has been included. As it is a design-based approach, each consultation round offered insights for incremental improvements (van den Akker, 1999).

RESULTS

The workshop results are discussed in the following sequence. First the sample group is briefly described. Then the resonance in terms of presence of certain behaviours on a dimension and the emergent behaviours are summarised. Successively, the numerical results (descriptive frequencies) of the workshops are presented in the table and aggregated at the end of the table (total). After the table a summary is presented of the comments made with respect to each variable: relevance, appropriateness, strategic value and inspiration. Each section closes of with a conclusion on the commentaries of the workshops.

	Emerging roles	Workshop 1 M =	Workshop 2 M=	Workshop 3 M =
1	origineering	5.8	5.8	5.9
2	swarmeneering		5.9	
3	engagineering			5.1
4	Ingrain- eering		5.1	
5	tinkeneering	6.4	5.0	5.2
6	perfectioneering	5.8	5.7	
7	Imagineering			5.4
8	fundamentaneering	5.7	5.0	5.0

In workshop 1. at the Dutch Design Week (n= 12), workshop 2. at the Teaching Lab and workshop (n= 7) 3. at 'Lijm en Cultuur' (n=13) different stakeholders attended, ranging from designers, artificial intelligence experts or and experts in the field of education leaders. Most of them assessed origineering, tinkeneering and fundamentaneering as emerging roles. Two of the roles are described in Fig. 4. Fundamentaneering being Phenomon, Slow and System driven is at the other end of the dimension. Participants felt origineering was strongly present already.

Table 1. Descriptive Frequencies of Variables on Likert Scale 1 to 7

Workshop 1	N=	1	2	3	4 (neutral)	5	6	7 (extremely relevant)
Relevance	10				1	1	8	
Appropriateness	10			1	3	2 (1= 5.5)	3	1
Strategic Value	10				1	1 (4.5)	4	4
Inspiration	13				1	5 (1 = 5.5)	7	
Workshop 2	N=	1	2	3	4 (neutral)	5	6	7 (extremely relevant)
Relevance	4					1	3	
Appropriateness	8			1	4		2	1
Strategic Value	10				2	5	2	1
Inspiration	6		1			1	4	
Workshop 3	N=	1	2	3	4 (neutral)	5	6	7 (extremely relevant)
Relevance	13				3	3	5	2
Appropriateness	16			3	4	4	4	1
Strategic Value	13		1		3	3	4	2
Inspiration	12			1		2	5	4
Total	N=	1	2	3	4 (neutral)	5	6	7 (extremely relevant)
Relevance	27				4	5	16	2
Appropriateness	34			5	11	6	9	3
Strategic Value	33		1		6	9	10	7
Inspiration	32		1	1		8	16	4

- The numbers in this table indicate the Likert scale scores from 1 to 7 in the columns and in the rows the descriptive frequencies scored on these scales for a particular variable. So in workshop 1. 10 people scored the variable relevance, of which one person on scale 4, one person on 5 and eight people scored 6.

Relevance

With the question “Is the framework relevant for Engineering Education? We investigated whether the model on the diversity of roles engineers can have in the future could be used to (re)design engineering education and whether it was relevant for the engineering field. The expertise of the workshop participants was crucial, as they had to relate their feedback to their own field of practice. Each field of practice was different for each workshop sample.

W.1. With respect to the question “is this framework **relevant** for the engineering field? ”, 8 out 10 answers, scored this question with a 6. This means the framework is very relevant for the engineering field. Remarks amongst others were; “*A very useful context analysis translated to a practical 3D framework”. “A Framework to dive deeper into engineering and thinking about the future of the engineer*”. “*It allows for roles to function as themes on a spectrum in education*”. “*Engineering is a process of compaction, choosing out of endless possibilities and should be allowed to be debated and grow*.”
W.2 In workshop two, the participants felt **relevance** was hard to assess as 1.) the model lacks future scenarios and 2) it is difficult to gauge what the framework should be relevant for. It may also have been caused by the un-clarity about the perspective commenters had to take to address this framework.

W.3 Seven out of 13 have found the framework **relevant** in workshop 3, especially at the contextual level the dimensions provides a point of departure "*to help student think of what they want to become*" or use it as "*a growth model*" to discuss student ambitions. At the same time, it is stated that the framework describes situations, in terms of norms and values, which need further validation in real life situations. This is tied into the question "*How many of these behaviours/interactions are already signalled in the world of companies?*" Finally, it is questioned whether the dimension "source of engagement" is really so interesting and if it should not be "Challenge" only instead of challenge vs phenomenon.

Overall, 50% felt the framework was very to extremely relevant. Which we interpret as having a framework which contextualises the engineering world of 2030 in a representative way. It warrants a further exploration of concept designs for engineering education programmes.

Appropriateness

The appropriateness questioned the ethical aspects of the framework. "Is it responsible to use this framework?" and "does it constructively affect the engineering field, the students and/or education?".

W.1. The **appropriateness** was more of a discussion issue as opposed to the relevance, with varying scores from 3 to 7. In the discussion participants questioned the appropriateness of the framework for a non-Dutch context, non- white male academics and women. Beside the cultural aspect they questioned, the lack of taking the 4^{th} Industrial Revolution into account. It was questioned whether AI/Robotics take over large parts of our future engineering jobs and part of these roles. Furthermore, they felt the risk of putting people into a pigeonholes is latent.
W.2 In the second workshop it was deliberated whether the framework would incite demand driven engineering education, in which only the educational scientists or industrial view would count. The belief is that education should be curiosity driven and not market driven. Despite the participants fears they also felt *"It is good to take social engineering, society and environment, as variables beyond technology, into account for any curriculum"*.

The response of the Artificial/Robotics specialists was as follows.
AI: With respect to AI/robotics it is stated that the merging and utilisation of AI technologies and models in robotics, such as artificial intelligent robotics and ethics will be a major dimension. It requires deep knowledge of artificial general intelligence, machine learning, deep learning, fuzzy ethics and legal education of(social) intelligent agents design and developments, programming and automatic control (control theory). It is likely that people focus even more on a specific knowledge area, although you do have a general knowledge about the other engineering roles".

W.3 The group was a little more divided about the **appropriateness** of the model. Most felt there was a risk in there to pigeon-hole the students. It was more a framework for talent development, discussion and an open choice for students to work on these talents. As such it was considered appropriate to implement it in education as a developmental direction.

Although there were many questions with regard to appropriateness, 50% still scored this as being moderately to extremely relevant. We expect that with a slight redesign, adapting to some of the criticism, the framework will gain in appropriateness for the engineering domain.

Strategic Value
Strategic value addresses whether the framework is useful for planning higher education programmes. "Does the framework support decision making processes with respect to the future of engineering in higher education?"

W.1. In workshop 1, the majority considered the framework as a valuable **strategic** planning tool for higher education (in particular in the Netherlands and possibly Western Europe). "*It helps to think strategically and yet become practical*". "*It provides insight into necessary skills and it is a good platform to start a conversation on new (piloting) programme*s."
W.2 The **strategic value** is that it allows programmes to push engineering education into a certain direction, yet it all depends on the acceptance level, and the open mindedness of the institution to new ways of learning. It should incite discussion on educational settings, discussion which are necessary to practice these or any role in engineering.
W.3 **In workshop 3,** 9 out of 13 participants were positive about the **strategic value**, yet only 6 saw a latent potential in the framework to rethink engineering education. More as in "*it is always relevant to think about renewal education, it helps critical reflection, but it could also be any other model".* The explanation ranges from, "*everything should be crystal clear to be able to work with the framework*", to "*these can be potential driving values for repositioning*", "*if the community is open to drastic change*".
Across the board around 75% considered the framework to have strategic value for higher education to start a discussion or to rethink engineering. Yet the participants feel there are a number of obstacles that need to be addressed . These are 1) the risk of creating demand-driven education 2) resistance to (radical) change of organisation and staff and 3) a lack of open-mindedness towards new ways of learning. Finally, participants questioned "*why we should use this model and not any other for that matter*". Which means the value proposition needs additional attention in follow up activities.

Inspiration

Inspiration is the last variable questioned. "*Is the framework a source of inspiration to create "new" types of engineering education"?*

W.1. Most participants in this workshop felt it was an **inspirational tool** to elaborate on the possible higher education programmes for the future. "*it is interesting for young people to know which role they play in the engineering world"*. "*It is a way to structure the future in other then just words and predictions*". "*it is helpful to making choices in future careers of current engineers, nice framework*" and "*grip in a complex world*" were some of the remarks made.
W.2. "*It is an **inspirational** toolbox that if used every 2 to 3 years will improve insight*". "*It offers a whole new framework to think about the form and content of education/project work*". "*It does challenge us to give new meaning to creativity"*
W.3 Most of the people in this workshop were convinced of its **inspirational** value. The participants stated, "*it is a toolbox, to look differently at education", "to explore new options", "to create new innovative concepts of courses", and "it opens up new venue's*". The dimension are felt to be complete, yet give a context to move around in.

Overall 85% of the workshop participants felt the framework offered an inspirational tool or toolbox to think about and develop engineering education for the immediate to long-term future.

DISCUSSIONS AND CONCLUSIONS

Most of the participants with whom we have discussed the framework felt it is relevant, of strategic value to higher education and the engineering field and certainly an inspirational tool to personalise and differentiate engineering education for the "near" and far future (2030). The framework is relevant as the dimensions are considered representative of the emerging future context and are partly recognised as being already present. The strategic value is that the framework is stimulating a more diverse approach to higher engineering education programmes and challenges policy makers, programme directors and others involved in curriculum design to think differently about the future engineering education programmes. This approach allows for diversification and adaptation to personalised learning for both students and alumni. The added value for society is that we will be offering newly developed education programmes, matching the future societal and emerging context of 2030. The value driven behavioural perspectives allow for agile adaptation to the world to come.

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