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OLD PROCEDURE - NEW APPROACHES: QFD WITH CHATGPT - COMPREHENSIVE PRODUCT AND PROCESS UNDERSTANDING IN ENGINEERING DESIGN EDUCATION

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ABSTRACT
Quality Function Deployment (QFD) is a well-established procedure that helps to translate customer needs and expectations into advantageous product features. A key element is the matrix-based 'House of Quality' (HoQ). Its different sections guide engineers through the process by addressing the customer's needs and expectations, defining specifications, finding how these parameters are interrelated, weighting them, evaluating and defining target values with help of a competitor analysis. But is QFD worthwhile teaching? What benefits can be seen? This article opens up new educational and engineering perspectives by presenting QFD examples, an analysis based on Artificial Intelligence (AI) using ChatGPT, and two surveys among students. The results demonstrate that QFD and the HoQ are still state-of-the-art procedures worthwhile being integrated in today's engineering education. The authors show new approaches, aspects, insights and reflections – but most of all let the users, respectively students evaluate this "old procedure with new approaches." This extension enables QFD to sustain comprehensive engineering and to support creativity – also integrating AI.

Keywords: QFD, Quality Function Deployment, engineering products, processes in engineering design and development, AI support in QFD, AI guideline for students and scientific thesis

1 INTRODUCTION AND RESEARCH MISSION
Quality Function Deployment (QFD) was developed and introduced by Yoji Akao in the late 1960s [1]. In the time of strong functionally organised companies, QFD had the aim to support engineers to get a deeper understanding of customer needs and expectations – expressed by the voice of customer (VoC) and the mind of customer (MoC). QFD was also set up to support the cross-functional understanding of the customer's needs and requirements, helping to engineer beneficial products that satisfy or delight customers instead of losing the customer focus by 'over-engineering.'
Since that time, engineering has shifted from functional organisation to an 'integrated design and development.' Major aspects of this change involve interdisciplinary and cross-functional teams, simultaneous engineering and tend to integrate customers in the engineering processes.
In this context the following questions arise and define our research mission:

- Is QFD still state-of-the-art?
- Does QFD help engineers today?
- Should students be acquainted with QFD and be able to apply the method?
- If QFD still has its 'right to exist': How should students be trained to apply it?
- How can students and engineers be motivated to employ QFD?

2 CONTEXTS IN ENGINEERING STUDIES
Mechanical Engineering students typically get in contact with Engineering Design and Development from the very beginning of their studies. While learning the 'handcraft 'of designing with help of CAD they simultaneously attend lectures in mechanics, technical drawing, machine elements, material sci-

ences and production processes. At Baden-Wuerttemberg Cooperative State University (DHBW), students in the engineering design programme today already explore product development processes and models in their second year. Thus, initiation to the V-Model, VDI guideline 2221, Cooper's stage gate system or the notion of 'Time to Market' (TTM) takes place earlier than usual. The reason for preponing the corresponding lecture in the study programme was that students lacked experience when they went – according to the cooperative study model – working six months on projects in companies during the second year. During the course of these projects Engineering Design students often support experienced project managers in developing and optimising products and processes. As a result of this curricular change, students are well prepared now to apply the concepts and methods they became acquainted with in the lecture into practice.

QFD is taught in the lecture 'Quality Management' that is scheduled in the third year of the Mechanical Engineering curriculum at DHBW (which is also the prevalent instant for this lecture at most universities in Germany). As we point out later, this timeline has proved to be beneficial: engineering design lecture followed by the internship in the second year and quality management in third year. This timely order allows students to deepen their knowledge on processes and to link engineering design to quality management procedures.

3 QFD TEACHING CONCEPTS

QFD and its House of Quality (HoQ), as well as subsidiary methods to accomplish the steps of the procedure more efficiently, Figure 1, have been constantly refined. As a result, QFD is a prominent tool in today's engineering world.

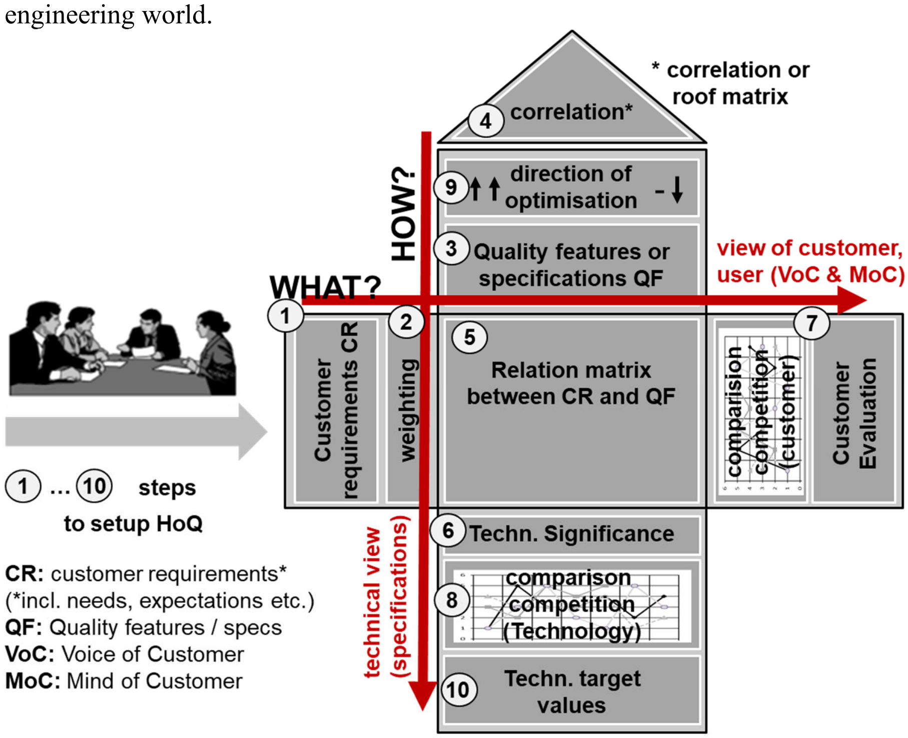


Figure 1. The House of Quality (HoQ)

There are even specialised institutes dedicated to QFD, offering trainings and workshops. Also, many publications about adaptions, integrating marketing and engineering methods, addressing best practise examples of applications with products, services etc. can be found [2], [3]. An overview is challenging but some publications try to summarise the milestones and refinements of QFD [4], [5]. The 'four phase model' was introduced by Sullivan, Hauser and Clausing and further developed by the American Supplier Institute (ASI), taking QFD from product, to part, to process and to production planning [4], [6], [7]. In 2015 the ISO standard 16355 was published in its first edition [8]. Today it consists of eight parts and surely is an expert standard. Also, within the domain of education a number of publications address challenges and attempts of teaching QFD. The application of QFD seems challenging. It is often exposed to criticism if only the HoQ is used as a method of implementing QFD. It is also said to be very expert related and time consuming if used as a set of adaptable matrices, as in the sense of the 'matrix of matrices' considered by Akao and King [9] or ISO 16355 [8] with its eight parts and the diverse tools and methods being proposed therein.

3.1 Traditional Teaching and Student-Centred Approach

A wide range of publications that derived an educational concept of teaching QFD, prefer a 'simple approach 'for using the HoQ: They advocate an efficient and motivating approach [10]. According to these studies, a lecture on QFD should be structured in the following steps:

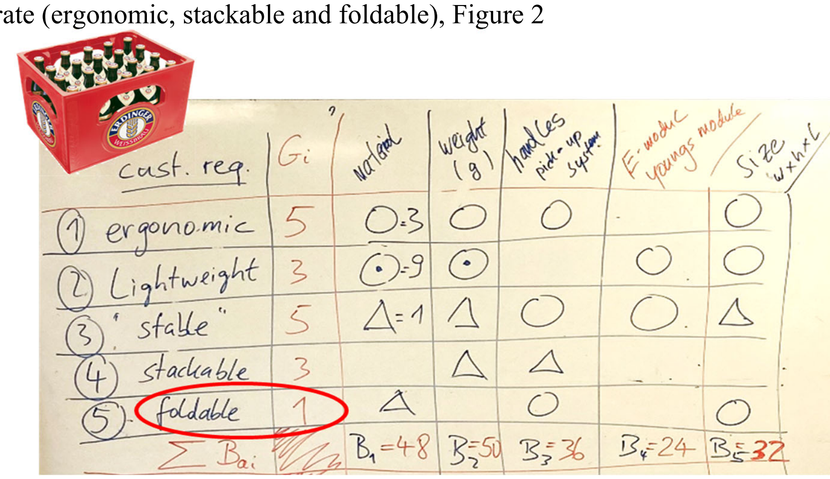
- Teaching the basics, theory and philosophy of QFD and HoQ, based on an already existing engineering knowledge from other lectures (enumerated in the section before)
- Applying QFD to a daily used product, letting students work their way through an own QFD project example (either as a lecturer moderated or as a group work exercise)
- Training with other given examples (either in a lecture, working in teams and supported by the lecturer, or as e-learning exercise, possibly even in a flipped classroom concept)

In the classroom, QFD exercises often are challenging. Particularly when it comes to finding target values. This requires competitor analysis, from the 'customer's view' and from a 'technical view,' Figure 1. This step requires an in-depth study by the students. Consequently, this option is usually only effectuated by a small group of students (10 %) on a voluntary basis. The reason is simple: This step requires additional time – more time than usually available during a lecture. Lecture time spent on QFD within the frame of a 'Quality Management' lecture typically is only three to five hours. On the other hand, Schockert and Schönhofen [10] sum the needed time up to 32 hours. This, of course, allows in-depth analysis. This approach surely is applicable for an elective QFD course but not within a comprehensive lecture on Quality Management that in total only spans 60 hours of lectures time.
The 'traditional' teaching concept can be characterised as a 'teacher-centred' approach where students learn theory and apply it on given, pre-defined problems. A more motivating concept is letting students choose their own QFD product. The role of educators is in assisting them by working their way through the QFD in teams. This can be classified as a more 'student-centred' approach [11].

3.2 QFD product examples fostering creativity

Some of the best and most creative product examples found by students in recent lectures on QFD at DHBW are listed below:

- Thermos flask or thermos cup: (vacuum insulated)
- Catapult: mobility and competitor product to fire-fighting vehicles or aircrafts and sprinklers
- Transportable, wireless loudspeaker (waterproof)
- Beer crate (ergonomic, stackable and foldable), Figure 2



G_i weighting index, cust. req. customer requirements, B_{ai} ratings

Figure 2. The core matrix of the House of Quality (HoQ) for a beer crate

Even if a beer crate seems rather simple at first sight, applying QFD generated several aha effects, Figure 2. Today´s customary solution possesses integrated handles and is stackable. The design tries to optimise between stability and lightweight. All in all, a product with a high level of maturity that will be hard to challenge. Nevertheless, one student produced an innovative feature in a lecture: a foldable crate. Good discussions evolved from the weighting of the customer requirements by applying a pairwise comparison matrix. Interestingly, the new idea of a foldable crate was rated low (=1 on a five-point scale in Figure 2) in comparison to the other customer requirements. This shows that 'out-of-the-box' product approaches often need a corrective intervention.

3.3 Integrating AI in teaching QFD

The integration of Artificial Intelligence (AI), in this case of the large language model (LLM) ChatGPT, can pave the way through QFD. In our study ChatGPT was prompted with questions that QFD users would also ask in a conventional approach:

1. I need a good innovative product to do a QFD, Quality function deployment, in my Quality Management lecture. So please name suitable products and functions or features for the product and quality!
2. Which are typical Customer Needs for this product?
3. Now translate or derive Engineering characteristics!

ChatGPT 3.5 answered these questions as follows:

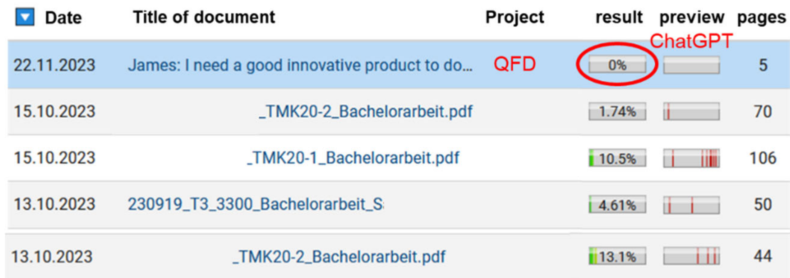
1. "(…) Let's consider a hypothetical innovative product - a 'Smart Home Health Monitoring System.' (…) Here are some potential functions or features (…)" - altogether ten aspects are listed with descriptions, e.g. from biometric and environmental sensors, data security and privacy to customisable alerts and notifications.
2. The second question is answered by listing twelve customer needs, some of them similar to the answer of the first question. Some are: a real-time health monitoring system, user-friendly interface, compatibility with other systems and continuous self-learning and improvement of the system.
3. The third question is answered respectively with detailed engineering features and refers to possible solutions, e.g. a real-time health monitoring with a high frequency sensor sampling, low-latency data transmission, compatibility with common smart home protocols, e.g. ZigBee, Z-Wave."

Students involved in the study felt that ChatGPT can support them well in gathering features for a product in a rather unknown field. In conventional lectures this objective is attained with help of creativity methods. To the educators leading the experiment the quality of the results seems adequate to the educational level. In addition, the answers were generated in only a few minutes.

3.4 Understanding AI and guidelines for application

In a subsequent step of this study, a documentation of the prompts and answers of ChatGPT were analysed with help of a plagiarism software. The results of this analysis, detailed in Figure 3, were discussed in the context of scientific writing in class, taking bachelor theses as an example. It could be observed that the students were really surprised by the plagiarism test. As a result, an intense discussion engaged – both between the class and the lecturer and within the class. Unexpected at this point, the discussion added a motivating momentum to the course.

According to the documentation of the plagiarism software, documents usually exhibit a similarity index between 1 % and 2 %. Furthermore, the developers of PlagAware judge less than 1 % as no significant infringement, 1 % to 5 % as a tolerance band, and more than 5 % as significant [12]. The ChatGPT answers on QFD, listed in the first row of Figure 3, showed no match (0 % resemblance) in two different plagiarism systems (PlagAware, Copyleaks). In return, Copyleaks identified that the text was written by AI with a probability of 100 %. In order to get a feeling for reference values, the artificially generated description of customer needs and product features have been compared to four bachelor theses handed in lately. The benchmarked documents obtained a score from minimum 1,7 % to maximum 13,1 % (PlagAware, 20.11.23). A critical rating of 13,1 % has been attributed to a thesis that is only 44 pages long and plagiarised half a page cited literature with no literature reference. The other thesis, some of them also rated critically, proved not to be a plagiarism. References were found and literature reflected. Plagiarism software can aid but still requires in depth analysis of plagiarised suspected text. But how should scientific research deal with AI if its use can't be proved – only recognized by some means?



Date	Title of document	Project	result	preview	pages
22.11.2023	James: I need a good innovative product to do...	QFD	0%	ChatGPT	5
15.10.2023	_TMK20-2_Bachelorarbeit.pdf		1.74%		70
15.10.2023	_TMK20-1_Bachelorarbeit.pdf		10.5%		106
13.10.2023	230919_T3_3300_Bachelorarbeit_S		4.61%		50
13.10.2023	_TMK20-2_Bachelorarbeit.pdf		13.1%		44

Figure 3. Results from plagiarism tests

After having explored miscellaneous possibilities of integrating AI into QFD, students discussed guidelines for using AI. The guidelines presented hereafter are intended to prepare students for their bachelor thesis. With the fast emergence and terrific progression of AI, many universities felt compelled to establish guidelines, some even replaced examinations with orals or introduced additional colloquia.
The following 'Seven rules for AI' have been setup [13] in this study:

- Use AI as a supporting tool to derive new ideas!
- Beware of prompting sensitive material which may be confidential!
- Question and reflect on results generated by AI! Be critical!
- Consult (scientific) literature in the specific field! This will help to reflect if data given, and ideas generated by AI are valid. AI may be biased!
- Document the use of AI tools! AI is not an author! [14], [15]
- Indicate precisely when data has been given and texts, codes or ideas have been generated by AI! Document prompts - if possible! Coding might be generated in a context, so document progression!
- Protect and respect the values of our society, laws, rules and human rights, such as copyright, privacy protection policy, personal rights and human equality!

4 SURVEYS ON QFD AND AI

Based on the fruitful discussions in class, students were asked to share their experience with QFD in connection with AI and to describe their motivation to use it in a survey.
Two classes participated: Mechanical Engineering students in Engineering Design and Electrical Engineering students in Automation. The total number of participants was 29.
The biggest difference between the two classes manifests in a question on the use of AI: While 73 % of the Automation students state that they use AI regularly, only 17 % of the Engineering Design students do so. 72 % of the latter class declare that they are still in the phase of trying out AI so far. The cause probably lies in the different field of use: While most Engineering Design students regard AI as a support for creating ideas and as a source of information, the Automation students rather deem AI to assist them in writing and coding (programming). In comparison, only one Engineering Design student mentioned programming. Across both classes, 93 % of all students intend to use AI in the future. Potentially, this general approval rests on the positive experience from the course described in section 3.3. A gradually weaker but nonetheless clear reaction was provoked with respect to a code of conduct. Over 80 % of the students agreed on the necessity of defining such guidelines for the use of AI. Nota bene, in order to exclude bias, the guidelines mentioned in section 3.4 were presented to the students after the survey.
The survey dedicated to QFD provides the following results (quoted hereinafter in consolidated form):
Over 75 % Engineering Design students think that QFD leads to innovative solutions while only 50 % Automation students do so.
Interestingly, only 47 % Engineering Design students consider QFD to procure a better product understanding while 92 % Automation students consent on this issue. This rather damped enthusiasm among the Engineering Design students seems incoherent with other results. Maybe the product example of a beer crate, the students chose, was 'too simple.' Consequently, QFD could probably not deploy its full strength: QFD particularly pays off with products revealing complex relations, e.g. in mechatronic applications. The method proved to appropriate some previously incomprehensible problems (cf. section 3.2 on the implied aha effects) very well.
Students (96 %) quasi-unanimously advocate embedding QFD and the HoQ in their curriculum.
In average, the applicability of the HoQ was graded with 2.3 on a Likert-type scale reaching from 1 (very good) to 5 (very poor). Engineering Design students assigned a slightly better grade (2.1), probably

because they are more accustomed to using methods, e.g. creativity and assessment methods, than their fellow students majoring in Automation.

5 CONCLUSIONS AND OUTLOOK

The interviewed students responded very positively on QFD, although the engineering world has changed considerably since Yoji Akao developed the method in the mid-1960's. The great esteem that the students attribute to QFD suggests that the chosen student-centred learning approach, which includes the free choice of a product example, was beneficial to the learning process. In particular, the students liked the experiment of tackling the 'old' procedure QFD with a 'new' approach (AI).

Other findings from the study are: The chronological order of lectures on Engineering Design, practical experience in industry within the co-op programme and a Quality Management lecture fosters deepening knowledge on engineering processes, also recognising how Engineering Design and Quality Management procedures closely engage. Applying QFD in engineering education also trains typical engineering tasks, as determining customer needs, defining product specifications, assessing solution variants according to rating criteria and analysing competitors. Altogether, discussions of how to integrate AI into QFD lead to a comprehensive product and process understanding in Engineering Design education.

Future work will expand the focus and encourage students to apply AI to other methods. Also, the educational concept will be further refined, reinforcing learning-centred application by flipping the classroom.

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