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# ALIGNING ASSESSMENT RESULTS WITH LEARNING OUTCOMES

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**ABSTRACT**
Competence-based education concentrates on learning outcomes instead of meticulously prescribing what to learn. A major problem for many lecturers and programme directors today is the lack of practical methods when it comes up to practical implementation. The paper describes a structured method that helps educators to map which learning outcomes they already address in their teaching. The presented step-by-step procedure is based on the QFD approach. The article leads the reader through all areas of the correlation matrix and exemplifies the procedure by presenting its implementation in an Engineering Design course of a BEng programme in Mechanical Engineering.

*Keywords: Competence development, assessment methods in Design Education, Quality Function Deployment (QFD), student learning outcomes, design-build-test experiences.*

## 1 MOTIVATION

Competence-based approaches radically change the way of understanding the worth of teaching, especially in applied sciences like design-related education. According to the principles of these approaches, the aim of teaching is not to simply pass on ‘numb’ knowledge [1] but to enable students to put their knowledge into action. Thus, developing competences instead of administering knowledge forces educators to rethink the way they are teaching fundamentally.

Arguments published in the relevant literature that advocate this shift from knowledge to competences are impressively simple and incontestable. But most sources remain vague (or rather silent) when it comes up to practical implementation.

## 2 LEARNING OUTCOMES

Perhaps the most holistic way for assessing student learning is to focus on learning outcomes. According to the *European Qualifications Framework* [2] learning outcomes describe ‘statements of what a learner knows, understands and is able to do on completion of a learning process, which are defined in terms of knowledge, skills and competence.’ Learning outcomes ‘build […] bridges between formal, non-formal and informal learning’ and are hence ‘irrespective of the routes of acquisition involved’, cf. [3].

In literature, countless tabulations break down learning outcomes to different levels of detail, e.g. Angelo and Cross [4] list 52 items in their so-called *Teaching Goal Inventory*. A commonly used set of general criteria for measuring learning outcomes in Engineering Education is articulated by the *Accreditation Board for Engineering and Technology* [5]: Accordingly, Engineering programmes should prepare their graduates to attain

(a) an ability to apply knowledge on mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyse and interpret data
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(d) an ability to function on multidisciplinary teams
(e) an ability to identify, formulate and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate efficiently

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

In view of these ambitious demands the question is legitimate to raise if it is possible at all to teach and assess these professional skills. Undoubtedly, this will cause problems in traditional, and underpins the urgent need for developing new formats of teaching and assessment [6]. Of course, we cannot suppose that all lectures participate uniformly in the development of the students' skills. Skill-oriented assessment must be broken down, so that 'each […] exercise or assignment must be designed with the objective of teaching, practicing, assessing a particular sub-set of skills' [7].

## 3 QFD APPROACH

Based on Akao's work [8] (whose origins date back to the mid-1960s) a large number of Quality Management approaches for Product Development has been derived. The traditional *Quality Function Deployment (QFD)* is a typical two-domain matrix analysis where elements of different nature are opposed. The core of the general QFD approach – the so-called *House of Quality (HoQ)* – translates customer requirements into technical specifications.

The presented adaption of the QFD matrix for an educational purpose helps to relate WHAT the student learning outcomes are supposed to be with HOW these skills are currently assessed. In other words, the proposed method captures the 'voice of the profession' and helps to translate it into 'the voice of the examiner'. By analogy, this matrix could be called the *House of Competence (HoC)*.

The described method can start from any generic set of learning outcomes, e.g. the general criteria for accrediting Engineering programmes developed by the *Accreditation Board for Engineering and Technology (ABET).* Figure 1 provides a mathematical description of the developed procedure. It is subdivided into two parts. Part A of that procedure breaks down the academic assessment to the learning outcomes. In other words, it helps to find out which learning outcomes are addressed in a course or study programme (and how strong these relations are). Part B translates the individual marks from the grading categories into the set of learning outcomes, i.e. it gives a classified overview of the skills and competences that students have achieved in that course or study programme.

*Step 1: Grading categories – Voice of the examiner*

The first step in the approach consists in collecting the grading categories within a curriculum, a module or a teaching unit (depending on the level of detail examined). Weighting factors $W_{0j}$ are used for pondering the relative importance of the grading categories corresponding to point distributions of examinations or project grading schemes. By definition, the sum of the weighting factors equals the multiplicative identify (=1).

*Step 2: Relationship matrix*

The 'heart' of the approach is the relationship matrix. It relates the grading categories listed in the columns to the learning outcomes in the rows. Numerical values $R_{ij}$ indicate if there is no, some, a medium or a strong medium or a strong relation between the two domains. As usual in QFD approaches, a progressive scale (0, 1, 3, 9) is used. After filling out the matrix, the fields contain the judgment of the educator if and in how far a certain learning outcome is addressed by a given test or in a given module.

*Step 3: Weighting matrix*

In a next step, the relative weight $W_{ij}$ of any relation $R_{ij}$ is calculated in a second matrix of identic size. Within every column (i.e. for every assessment category $j$), this value $W_{ij}$ expresses the relative importance $R_{ij}$ for a given learning outcome $i$ in relation to the cumulated importance to all learning outcomes. Besides, the ratio is normalised by the weighting of that column (assessment category) $W_{0j}$. In this way, the sum of all relative weights $W_{ij}$ within the matrix is 1 by definition. The highest values $W_{ij}$ indicate the most important relations.

*Step 4: Student outcomes – Voice of the profession*

Now, we can calculate the relative weightings $W_{i0}$ by summing up the rows. These sums tell us to what degree every single learning outcome is included in the course assessment. The highest values obtained identify the learning outcomes which are addressed most in the course or study programme.

Learning outcomes that are not addressed at all receive a nil value. If the interest is just in analysing the course or study programme, the procedure stops here.

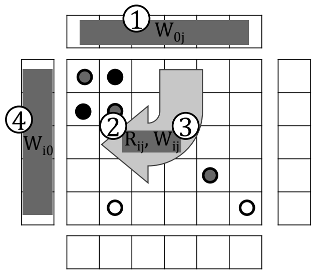
PART **A**

① Enter weightings $W_{0j}$ $(0 < W_{0j} \leq 1)$, check sum $\sum_j W_{0j} \stackrel{\text{def}}{=} 1$

② Determine relations $R_{ij}$ $(R_{ij} = \{0,1,3,9\})$

③ Calculate weightings $W_{ij} = \frac{W_{0j} R_{ij}}{\sum_i R_{ij}}$, check sums $\sum_i W_{ij} \stackrel{\text{def}}{=} W_{0j}$, $\sum_j W_{0j} \stackrel{\text{def}}{=} 1$

④ Calculate weightings $W_{i0} = \sum_j W_{ij}$

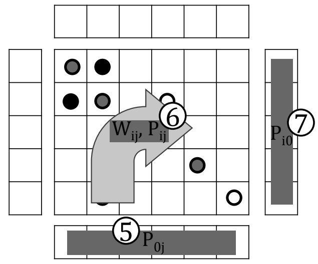



PART **B**

⑤ Enter points $P_{0j}$ $(0 \leq P_{0j} \leq 1)$

⑥ Calculate points $P_{ij} = P_{0j} W_{ij}$, check if $0 \leq P_{ij} \leq W_{ij}$

⑦ Calculate points $P_{i0} = \frac{\sum_j P_{ij}}{W_{i0}}$, check if $\sum_i P_{i0} \stackrel{\text{def}}{=} \sum_j P_{0j}$




*(● = 9 strong, ● = 3 medium, ○ = 1 weak relation)*

*Figure 1. Formal description of the developed procedure*

*Step 5: Assessment results*
For determining the student performance with respect to the learning outcomes, the procedure continues with Step 5. For this, we enter the assessment results in an extra-row. The points $P_{0j}$ should be comprised between 0 and 1 – where 1 means the top score.

*Step 6: Performance matrix*
In a third matrix of identic size, the weighted performance $P_{ij}$ is calculated. Therefore, the weighting matrix from Step 3 is multiplied by the points $P_{0j}$ in the column head (or rather in the 'column foot' according to our notation, cf. Figure 1). Systematically, the product should be inferior (or exceptionally equal) to the weightings $W_{ij}$.

*Step 7: Performance classed by learning outcomes*
Finally, we can calculate how well learners performed with respect to the single learning outcomes considered in the course or study programme. In order to do so, we sum up the relative points $P_{ij}$ row-wise and divide them by the relative weightings of the rows $W_{i0}$ from Step 4.

## 4 APPLICATION TO PLAN-BUILD-TEST LEARNING EXPERIENCES

In the following, we want to exemplify our procedure by a typical undergraduate course on Engineering Design of an BEng Mechanical Engineering programme at our university. Over time, we have developed a course format that is based on project-oriented learning and has a strong focus on facilitating students to acquire design-build-test experiences. Table 1 lists projects from the recent years. In all projects, students had to solve typical mechanical transmission problems and all products (except for the mini-quadcopter in project E) are driven by a cordless powerdrill.

*Table 1. Recent design-build-test projects at DHBW Cooperative State University* cf. [9]

| | *year* | *sem* | *#* | *product* | *SP* | *AM* |
|---|---|---|---|---|---|---|
| A | 2013 | 3 | 52 | Electrically driven go-kart | X | |
| B | 2014 | 3 | 84 | Winch for launching non-motorised model aeroplanes [10] | X | |
| C | 2015 | 3 | 67 | Small helicopter rotor and starting device | X | X |
| D | | 4 | 65 | Strain wave gear (Harmonic Drive$^{TM}$) [11] | | X |
| E | 2016 | 2 | 76 | Mini-quadcopter (Flexbot) for transporting matchboxes [12] | | X |
| F | | 3 | 81 | Electrically driven go-kart | X | |
| G | | 4 | 72 | Centrifugal clutch | X | X |

*sem* semester, # number of participating students, *SP* supply parts, *AM* additive manufacturing

Since the manufacturing of parts is always a critical issue in design-build-test projects, we either ask our students to configure their products entirely with parts from a supply parts catalogue (as in project A, B and F) or to build their products with help of Additive Manufacturing systems – such as a laser sintering system or fused-deposition modelling 3D-printers – (project D and E), or by combining both (project C and G).

For the purpose of demonstration, the Figures 2 and 3 compare two different course assessment modes. The first table (Figure 2) exclusively considers a written examination. The second table (Figure 3) additionally includes the assessment of a student project. The four problems of the written examination in that first-year Engineering Design course ask the students to prove the strength of Machine Elements (problem E1 and E2) and to apply Product Development methods (problem E3 and E4). The student project was graded by a broad fan of activities – namely an assignment during the formation of the groups (P1), the generation of concepts (P2), the adherence to deadlines for the 3D-printing of parts (P3), the technical documentation including the manufacturing drawings of the components (P4), and the functional testing of the 3D-printed products (P5).

| | | assessment | | | | |
|---|---|---|---|---|---|---|
| | | written examination | | | | |
| | | E1 leaf spring | E2 bolt calc | E3 morphol. box | E4 assessment | |
| | weighthing | 0,23 | 0,53 | 0,04 | 0,20 | |
| a) STEM knowledge | 0,46 | 3 | 3 | 1 | 1 | 0,62 |
| b) experiments | 0,09 | | 1 | | | 0,60 |
| c) Design for X | 0,06 | | | 3 | 1 | 0,77 |
| d) teamwork | | | | | | |
| e) problem solving skills | 0,20 | 1 | 1 | 3 | 1 | 0,65 |
| f) ethical responsibility | | | | | | |
| g) communication | | | | | | |
| h) impact awareness | | | | | | |
| i) life-long learning | | | | | | |
| j) contemporary issues | | | | | | |
| k) engineering tools | 0,19 | 1 | 1 | 1 | 1 | 0,65 |
| learning outcomes | | 0,59 | 0,60 | 0,64 | 0,81 | grading |

*Figure 2. 'House of Competence' for a course assessed by a written examination*

The *House of Competence* in Figure 2 shows how 'poor' the assessment is – especially in design-related sciences – when it purely relies on a written examination. If there was only a written examination, mainly STEM[1] knowledge would be tested (0.46). Problem solving skills are also somehow trained (0.20) and engineering tools have to be employed rudimentarily (0.19). But all the other learning outcomes are almost irrelevant or literally not addressed at all. The shading in grey nuances indicates the strength of the correlations in the matrix according to the relative weightings $W_{ij}$.

[1] The acronym stands for Science, Technology, Engineering and Mathematics.

| learning outcomes | weighthing | E1 leaf spring | E2 bolt calc | E3 morphol. box | E4 assessment | P1 grouping | P2 concepts | P3 3D-printing | P4 drawings | P5 testing | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | written examination | | | | student project | | | | | |
| weighthing | | 0,12 | 0,27 | 0,02 | 0,10 | 0,03 | 0,08 | 0,00 | 0,20 | 0,20 | |
| a) STEM knowledge | 0,28 | 3 | 3 | 1 | 1 | | 1 | 3 | 3 | | 0,64 |
| b) experiments | 0,13 | | 1 | | | | | 1 | | 9 | 0,84 |
| c) Design for X | 0,09 | | | 3 | 1 | | 3 | 3 | 1 | 3 | 0,83 |
| d) teamwork | 0,08 | | | | | 1 | 3 | 9 | 3 | 1 | 0,81 |
| e) problem solving skills | 0,11 | 1 | 1 | 3 | 1 | | 3 | 3 | | | 0,67 |
| f) ethical responsibility | 0,01 | | | | | | | | | 1 | 0,97 |
| g) communication | 0,08 | | | | | 1 | 3 | 9 | 3 | 1 | 0,81 |
| h) impact awareness | 0,01 | | | | | | | | | 1 | 0,97 |
| i) life-long learning | | | | | | | | 1 | | | |
| j) contemporary issues | 0,04 | | | | | | 3 | 9 | | 3 | 0,92 |
| k) engineering tools | 0,18 | 1 | 1 | 1 | 1 | | 3 | 9 | 3 | 3 | 0,73 |
| grading | | 0,59 | 0,60 | 0,64 | 0,81 | 1,00 | 0,80 | | 0,73 | 0,97 | |

*Figure 3. 'House of Competence' for a course assessed by a written examination accompanied by a student project*

Lectures on Engineering Design are often accompanied by a student project. Our special concern is to brief students with tasks that require them not only to *plan* products, but also to *build* and *test* them. The result in the *House of Competence* in Figure 3 is much more 'equilibrated'. Still there is a high attention to STEM knowledge (0.28). But all except one learning outcomes are more or less addressed. This also enables to translate the students' performance into the domain of learning outcomes. The grading in the bottom-row corresponds to the average points achieved by 76 students in the different assessment categories. The column to the right represents the translation into learning outcomes. Please note that marks corresponding to low weighting factors imply a high level of uncertainty. A good example is the learning outcome 'impact awareness' (h): There is only a small relation (1) with the assessment from the product testing (P5). Consequently, the weighting represents only 1 % (0.01) of the whole. The average mark that the students received (0.97) therefore have to be dealt with the given measuring uncertainty.

## 5 DISCUSSION

In the form that we currently employed it, the presented QFD-based approach is a powerful instrument for individual lecturers that assists in checking if the delivered teaching matches the wanted learning outcomes. For us, it had an eye-opening effect and facilitated the search of adequate means of course assessment. Of course, the application of the approach is by far not limited to that field. In a broader context, the *House of Competence* could serve cross-disciplinary coordination between different educators. For them, an interesting question to be answered with help of the *House of Competence* could be to identify the courses in which it is most viable to address specific learning outcomes. Even on faculty level, the presented approach could serve as a strategic instrument for the planning of curricula – especially during (re)accreditation.

Thus, future work should extend the fields of application in order to examine the results that the proposed approach obtains in a broader context compared to the situations it has been applied to by now. For example, this includes to study how different academic institutions can align the obtained results with their own pedagogical concepts and visions. Future research should also compare the work to similar approaches, e.g. [13, 14]. This will also help to tell where QFD-based approaches encounter their limitations.

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