AC 2007-2126: USE OF QFD IN THE ASSESSMENT OF COURSE ACTIVITIES FOR LEARNING OUTCOMES

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Abstract

This paper describes the principles of Quality Function Deployment (QFD) used in the assessment of various student activities pursued during both classroom and laboratory instruction. Twenty two different types of student activities were analyzed for their contribution toward fulfillment of thirty learning outcomes. Some of the learning outcomes considered in the presented analysis were identified by Engineering Technology faculty for program assessment purposes. Additionally, there are also other outcomes that were considered by both faculty and members of the Engineering Technology Industrial Advisory Board during the development stage of the program assessment process. In two senior level courses dealing with subjects of engineering design and manufacturing processes, each type of student activity was also assessed in terms of its level according to Bloom's taxonomy. Various assessment methods and observation are utilized in these courses to evaluate students' performance. Design projects, concept generation, individual formal presentations, information search and forensic studies proved to be the most universal activities, developing a wide range of professional skills.

After the initial analysis, for the purpose of feasibility of the assessment process, this large number of skills was reduced to a manageable number and grouped into ten learning outcomes. The ten outcomes became the subject of the formally accepted assessment process for Engineering Technology programs at CCSU.

Introduction

Quality Function Deployment (QFD) technique parallels engineering procedures used for establishing and examining product and process specifications and performances^{1,2}. Developed in 1970's in Japan and used in Kobe Shipyard of Mitsubishi Heavy Industries, QFD methodology stemmed from quality improvement tables and was originally used for development of new products³ (more details about past, present and future of QFD can be found in paper by Akao⁴). However, QFD is also a technique that helps in capturing, organizing and systematizing present knowledge about a product or process with a view of increasing the knowledge and making necessary improvements to meet future challenges^{3,5,6}. It is "the only comprehensive quality system aimed specifically at satisfying the customer"⁷. QFD uses voice of customer (VOC) and technical characteristics of a product or process as inputs. Using these two groups of inputs: VOC called also *Wants* or *Needs* or *Whats* and technical characteristics called also *Hows*, QFD study also aims at establishing relationships between the two groups. Strength of each relationship between each *Want* and each *How* is assessed according to degree of how a customer's want is influenced by a technical characteristic. Each relationship is assessed for its existence on lack thereof⁸, or more commonly a degree of strength of relationship is rated to have one of four levels: strong, medium, weak and negligible. To illustrate the degree of relationship in QFD matrix, most authors use symbols, some use symbols

and/or numerical values to quantify other outcomes of QFD study. Most often used values are: strong = 9, medium = 3, weak = 1, negligible = 0^{9,10}; although values of 9, 5, 3 and 0 respectively are used by some¹¹. Application of QFD process ranges from translation of customers' needs into a set of specifications for a new product, defining its feasibility, examination of Wants vs. Hows relationships in existing products, benchmarking and improvement efforts.

QFD can also be utilized in education for rigorous examination of existing programs. Wants are knowledge and skills wanted by employers. They are established by engineering faculty, Industrial Advisory Board (IAB) and discipline-related professional societies. Hows can be described as courses, learning modules, topics and learning activities. The relationships described in this paper illustrate evaluation of learning activities in five courses in Manufacturing Engineering Technology program at Central Connecticut State University.

Program Educational Goals and Means of Achieving Them

The analysis of the Manufacturing Engineering Technology program involved identification of knowledge and skills required of program graduates. These educational goals of the program became *Wants* in terms of QFD matrix. Courses required for graduation with BS degree in Manufacturing ET were treated as means of providing the knowledge and skills, hence these became *Hows*.

Matrix Development

Deployment of Customer Requirements (VOC) to Production and Quality Controls can be done in a sequence of rigorous five steps³ described in [Table 1](#). Each step comprises its own matrix with its own *What-How* (*Wants-Hows*) relationships.

Table 1. Deployment of Customer Requirements to Production and Quality Controls.

	Deployment step	Matrix	Wants	Hows
1	Product Planning	House of Quality	Customer Requirements	Design Requirements
2	Product Design I	Design	Design Requirements	Engineering Design
3	Product Design II	Product Engineering Characteristics	Engineering Design	Product Engineering Characteristics
4	Process Planning - Design	Manufacturing and Purchasing	Product Engineering Characteristics	Manufacturing and Purchasing Operations
5	Process Planning - Control	Control	Manufacturing and Purchasing Operations	Production and Quality Controls

In real life QFD study not all the steps must be used nor need to be used. The most common, and arguably the one casting longest shadow on the end product under development, is the first step – House of Quality. For purposes of evaluation of existing products, benchmarking products and processes, and other improvement efforts, Customer Requirements can be deployed directly against a higher level of end product related *Hows*, e.g. Product Engineering Characteristics. In the study described in this paper, learning outcomes (Wants) are deployed

against learning activities (Hows), which may be loosely equated to deploying customer requirements to manufacturing operations.

Choice of Learning Outcomes for Evaluation

Learning outcomes that became part of the approved assessment and evaluation process for the purposes of accreditation differ slightly from learning outcomes described in this paper. Learning outcomes described here are more detailed and serve the purpose of evaluation of learning activities used in teaching process. They stem from examination of vast literature on the subject¹²⁻²⁰ and professional experience of the author of this paper. They are listed in [Table 2](#). Various authors also use different approaches to the scope of application of their assessment, ranging from a single course²¹, through entire single program¹⁸⁻²⁰, to a group of related programs²³. In his licentiate thesis from 1997, Broberg describes various tools for learners as knowledge workers²². One of the noted tools, 'finding internal factors of relevance' is related to the described here continuous improvement efforts with a goal of efficient learning. Kauffmann et al. described successful application of QFD decision model to prioritize and select courses and curricular content for impact they have on program objectives²⁴. A different level of curricular involvement is presented in this paper, which concentrates on learning outcomes and learning activities which are supposed to foster student development in a multitude of ways.

Learning outcomes and procedures identified for the purpose of assessment and evaluation of the entire Manufacturing ET program at CCSU in accordance with TAC of ABET accreditation requirements were described in detail by Lema, Baumann and Prusak²³. Additionally, there are also other outcomes that were considered by both faculty and members of the Engineering Technology Industrial Advisory Board during the development stage of the assessment process for entire program in accordance to TAC of ABET accreditation requirements.

Table 2. Learning outcomes assessed for their relevance to learning activities.

LO #	Abbreviation code used in matrix	Desired learning outcome ((knowledge, abilities and skills)
1.	Engr Sci Know Base	Engineering and scientific knowledge base
2.	Use Know Base	Task-oriented understanding and use of engr. and sci. knowledge base
3.	Comp Tools	Knowledge and use of computer tools (CAD/CAM, FEA, data acquisition, data processing and graphing, reporting, presentation, etc.)
4.	Sketch	Ability to quickly generate hand sketches
5.	Engr Std	Knowledge of pertinent engineering standards
6.	Use Engr Std	Task-oriented understanding and use of pertinent engineering standards
7.	Interdisc Think	Interdisciplinary thinking
8.	Sysmtic Prob Evalu	Systematic and interdisciplinary evaluation of problems
9.	Analy Well-def Prob	Analysis of well-defined problems
10.	Analy Open Prob	Analysis of open-ended problems
11.	Analy Ill-def Prob	Analysis of ill-defined problems
12.	Solv Prob Team	Solving of problems in teams
13.	Org Team Work	Organization of team work
14.	Act Independently	Acting independently
15.	Org Indiv Work	Self-organization
16.	Writ Comm Tech	Written communication with technical people
17.	Verb Comm Tech	Verbal communication with technical people
18.	Writ Comm Non-tech	Written communication with non-technical people
19.	Verb Comm Non-tech	Verbal communication with non-technical people
20.	Comm Diff Culture	Communication with people from different cultures
21.	Persuade Negotiate	Persuasion, negotiation
22.	Info Search	Search for information
23.	Info Reduc Compil	Reduction and compilation of information
24.	Creativity	Creative thinking
25.	Systems Think	Systems thinking
26.	Value Engr	Value engineering
27.	Prof Ethics	Professional ethics
28.	Manners	Personal manners
29.	Work Under Press	Work under pressure
30.	Self Learn	Self learning

Choice of Evaluated Learning Activities

Majority of these learning activities are used continuously in five courses required in Manufacturing ET program at CCSU. Some of them were tried for a period of at least 3 semesters and dropped due to a variety of reasons: predominantly time constraints manifested in non-substantial contribution to learning outcomes for significant class time involved or students' study time involved. The five courses and Co-op are described in [Table 3](#).

Table 3. Learning activities assessed in QFD matrix.

Course level	Course name	Course type
Sophomore	Materials Processing	classroom / lab
Junior/Sophomore	Geometric Dimensioning & Tolerancing	classroom
Junior	Computer Aided Planning	classroom / computer lab
Senior	Manuf. Process Planning and Estimating	classroom / lab on occasion
Senior	Design for Manufacture	classroom / lab on occasion
Senior	Industrial Co-op	industry, full time

Table 4 provides list of learning activities that are evaluated through QFD matrix relationship for their usefulness in providing high level learning outcomes. Industrial Co-op comprising full time industrial experience is very difficult to assess due to lack of academic control and large variability between Co-op assignments. For these reasons, drawing on hundreds of interviews with students who finished Co-op, two types of Co-op experience were used for the matrix: excellent experience where a students is involved in planned and supervised activities, and poor experience where a student spends most time ‘putting down fires’ with no clear goals for achievement. As can be expected, majority of Co-op experiences are somewhere in between the two.

Table 4. Learning activities assessed in QFD matrix.

Act #	Abbreviation code used in matrix	Learning activity used
1.	Lect	Lecture
2.	Hw	Graded homework
3.	Read	Reading and self study
4.	Quiz	Short quiz
5.	Exam	Exam (midterm, final, etc.)
6.	Comp Lect	Computer lab lecture
7.	Lab Sh Exe	Laboratory hands-on short exercises
8.	Lab Expm Team	Laboratory experimentation – team work
9.	Forens Indiv	Forensic analysis in-class exercises – individual work
10.	Forens Team	Forensic analysis in-class exercises – team work
11.	Des Sh Exe Indiv	Design short exercises in-class – individual work
12.	Des Sh Exe Team	Design short exercises in-class – team work
13.	Des Proj Indiv	Design projects – individual work
14.	Des Proj Team	Design projects – team work
15.	Des Dev Lab Expm	Design and development of new lab experiments
16.	Concept Gener	Concept generation (Brainstorming, Synectics)
17.	Critique	Critique of own work and work of others
18.	Info Search	Information search and compilation assignment
19.	Pres Indiv	Individual presentation
20.	Pres Team	Group presentation
21.	Co-op excell	Industrial Co-op excellent experience
22.	Co-op poor	Industrial Co-op poor experience

QFD Matrices and Analysis of Results

Table 5. Deployment of learning outcomes to learning activities – QFD matrix for all courses listed in Table 3.

Codes for Learning Outcomes and for Learning Activities are in Tables 2 and 4 respectively.

Relationship code: ● = strong, ○ = medium, △ = weak, empty cell = negligible.

		Learning Activity																						
Learning Activity Code		Lect	Hw	Read	Quiz	Exam	Comp Lect	Lab Sh Exe	Lab Expm Team	Forens Indiv	Forens Team	Des Sh Exe Indiv	Des Sh Exe Team	Des Proj Indiv	Des Proj Team	Des Dev Lab Expm	Concept Gener	Critique	Info Search	Pres Indiv	Pres Team	Coop excell	Coop poor	
Learning Activity #		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
LO #	LO Code																							
Learning Outcome (LO)	1 Engr Sci Know Base	●	●	●	●	●	△	△	○	△	○			○	○	△		△	○	△		△	△	
	2 Use Know Base	△	●	○	△	○		△	●	○	●	△	○	●	●	●	●	●				●	△	
	3 Comp Tools		●			△								●	△					●	○	●	△	
	4 Sketch		△		△	△		△	△		△	○	○	○	△	○	○	△				○		
	5 Engr Std	●	△	○	△	○			△	△	△		△		△	○		△				●	○	
	6 Use Engr Std	△	●	○		△	△		△	○	○			△	○	△		△				●	○	
	7 Interdisc Think									○	○		△	△	△		○	△	△			△		
	8 Sysmtic Prob Evalu	●	●	●		△			○	●	●	△	○	○	△	●	●	●	○	△		○		
	9 Analy Well-def Prob	●	●	○	○	○	○	○	●	○	○	△	△	△	○	○	○	△	△			●	○	
	10 Analy Open Prob	○		△					△		△				○	●	●	△	○			●	△	
	11 Analy Ill-def Prob	●	△	△		△			△		△				△	△	○	△	○			○	△	
	12 Solv Prob Team								○		●		△		●		○				○	●	○	
	13 Org Team Work								△		○			△		●					△	●		
	14 Act Independently		●	●	●	●	○	○	△	△				○				△	●	●	●	●	△	
	15 Org Indiv Work		○			○	●	△	△		○			○	○			○	○	●	○	△	●	○
	16 Writ Comm Tech	△	△			△				●	○			●	○	○	●	△	●		○	○	●	○
	17 Verb Comm Tech								●		●					●	●	●	●		●	○	●	●
	18 Writ Comm Non-tech																	●				△		
	19 Verb Comm Non-tech																	●	●		●	○	○	○
	20 Comm Diff Culture			△					△			○				●	●	●	●		●	●	○	
	21 Persuade Negotiate								●		●		○			●	●	△	●			●	●	△
	22 Info Search		△							●	●	●		○	●	●	●	○	○	●	○	○	●	
	23 Info Reduc Compil		△			△				●	●	●	●	○	●	●	●	○	○	●	●	●	●	
	24 Creativity		○					○			●	●	●	●	●	●	●	●		○	△	△	●	
	25 Systems Think	○	△	○			○		△	●	●	△	△	△	○	△	●	●	●	○			●	△
	26 Value Engr	○		●							●	●			○	△	○		○				●	
	27 Prof Ethics	△	○	○	●	●			△	○	○				△	○	○		●		△	△	●	△
	28 Manners								△		△		△			△					●	●	●	△
	29 Work Under Press				●	●		○	△	△	△	●		○	●			●				●	●	○
	30 Self Learn		△	●			○				●	○			●	○	○		●	●			○	

It should be noted that Co-op total strength of relationship is double that of each other learning activity. It was clarified earlier in explanation of [Table 4](#). Most Co-op experiences are somewhere in between the excellent and poor.

Table 6. Comparison of usefulness of learning activities in fulfillment of learning outcomes for all courses listed in [Table 3](#). The higher the number the higher the usefulness. Codes for Learning Activities are in [Table 4](#). Relationship code shown in [Table 5](#) was substituted for calculations with numbers: ● = 9 = strong, ○ = 3 = medium, Δ = 1 = weak, empty cell = 0 = negligible.

		Learning Activity																					
		Lect	Hw	Read	Quiz	Exam	Comp Lect	Lab Sh Exe	Lab Expm Team	Forens Indiv	Forens Team	Des Sh Exe Indiv	Des Sh Exe Team	Des Proj Indiv	Des Proj Team	Des Dev Lab Expm	Concept Gener	Critique	Info Search	Pres Indiv	Pres Team	Coop excell	Coop poor
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	Learning Activity	58	80	66	42	55	26	13	67	91	126	34	31	91	123	120	105	128	65	76	67	210	43
	Usefulness																						
	Comparison																						

As explained below [Table 5](#), Co-op score should be viewed to be somewhere between 43 and 210. Its average of 127 should be taken for purposes of comparison with other learning activities. The group of learning activities having highest usefulness in fulfillment of learning outcomes (taking into account 5 courses listed in [Table 3](#)) consists of:

- Forensic analysis in-class exercises – team work
- Design projects – team work
- Design and development of new lab experiments
- Concept generation (Brainstorming, Syntectics)
- Critique of own work and work of others

Despite their average scores, the traditional rudimentary learning activities (lecture, homework, reading, quiz, exams) are the most useful in preparation of learner's knowledge base and skills of effective use of it. Short design exercises scored low, however their contribution in fostering creative thinking is very substantial. These exercises do not require a substantial allocation of classroom time; therefore can be repeated multiple times, further adding to their usefulness.

Table 7. Comparison of fulfillment of learning outcomes based on usefulness of learning activities for all courses listed in Table 3. The higher the number the more substantial the fulfillment.

Codes for Learning Activities are in Table 2.

Relationship code shown in Table 5 was substituted for calculations with numbers:

● = 9 = strong, ○ = 3 = medium, Δ = 1 = weak, empty cell = 0 = negligible.

Learning Activity Code		Learning Outcomes Fulfillment Comparison
Learning Activity #		
LO #	LO Code	
Learning Outcome (LO)	1 Engr Sci Know Base	68
	2 Use Know Base	98
	3 Comp Tools	42
	4 Sketch	26
	5 Engr Std	38
	6 Use Engr Std	40
	7 Interdisc Think	15
	8 Sysmtic Prob Evalu	91
	9 Analy Well-def Prob	74
	10 Analy Open Prob	41
	11 Analy Ill-def Prob	27
	12 Solv Prob Team	40
	13 Org Team Work	24
	14 Act Independently	85
	15 Org Indiv Work	54
	16 Writ Comm Tech	64
	17 Verb Comm Tech	84
	18 Writ Comm Non-tech	10
	19 Verb Comm Non-tech	36
	20 Comm Diff Culture	62
	21 Persuade Negotiate	68
	22 Info Search	76
	23 Info Reduc Compil	110
	24 Creativity	92
	25 Systems Think	75
	26 Value Engr	49
	27 Prof Ethics	60
	28 Manners	32
	29 Work Under Press	75
	30 Self Learn	61

Not surprisingly, learning outcome 'Reduction and compilation of information' came on top as the best fulfilled by the learning activities evaluated. The learning process is about information compilation and reduction even if little self preparation of students is required a lot of spoon feeding is practiced to enhance amount of material covered.

Interdisciplinary thinking, analysis of ill-defined problems, conveying technical ideas using hand sketches, and methodical organization of team work scored poorly. This is not a surprise, since

these skills either did not make their way to traditional engineering curricula yet or, as in the case of sketching are considered obsolete and were replaced with computer skills. Written and verbal communication with non-technical people does not find emphasis in the five courses considered here, due to the fact that it is emphasized in general education section of program curriculum. Another poor scorer, manners, is expected to be taught even earlier on, during K-12 education and at home.

Tables 8 and 9 illustrate learning activities used in two senior level courses required in Manufacturing ET program. Each activity used in the course is coded for level of its emphasis during the semester. For comparison of usefulness of learning activities, each activity usefulness score (as shown in Table 6) was multiplied by number pertinent to the level of emphasis in each course. For example, Lecture has 58 in Table 6, 9 for level of emphasis in Table 8, hence its score is 522. Bloom's Taxonomy level corresponding to for each learning activity as used in the courses is also shown in Tables 8 and 9.

Table 8. Comparison of usefulness of learning activities used in senior level course Manufacturing Process Planning and Estimating in fulfillment of learning outcomes. The higher the number the higher the usefulness. Codes for Learning Activities are in Table 4. Relationship code shown in Table 5 was substituted for calculations with numbers: ● = 9 = strong, ○ = 3 = medium, △ = 1 = weak, empty cell = 0 = negligible.

			Learning Activity																					
			Lect	Hw	Read	Quiz	Exam	Comp Lect	Lab Sh Exe	Lab Expm Team	Forens Indiv	Forens Team	Des Sh Exe Indiv	Des Sh Exe Team	Des Proj Indiv	Des Proj Team	Des Dev Lab Expm	Concept Gener	Critique	Info Search	Pres Indiv	Pres Team	Coop excell	Coop poor
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
			Level of emphasis in course																					
			●	○	●	△	●				△	△	△	○		●	△	●	△	●	●			
			Bloom's Taxonomy level																					
			1	2	1	1	2				4	4	3	3		6	5	5	5	3	3			
	Usefulness		522	240	594	42	495	0	0	0	91	126	34	93	0	1107	120	945	128	585	684	0	0	0
	Comparison of																							
	Learning Activities																							
	Used in Course																							

It is noticeable that for both courses summarized in Tables 8 and 9, usefulness of learning activities can be grouped into three categories according to their level of fulfillment of learning objectives. The grouping is base on scores in the bottom row.

- First category of most useful activities comprises: design projects done in teams, and concept generation.

- Second category comprises: individual presentations, information search compilation and reduction, assigned reading, lecture, exams, and for DFM course forensic analysis exercises done in-class as team work.
- Third category comprises the rest.

These two courses were chosen to provide assessment and evaluation data for continuous improvement efforts. Since these two courses are required in Manufacturing ET and Mechanical ET programs, the data is used also for purpose of TAC of ABET accreditation self study and continuous improvement of both programs (detailed description available in paper by Lema, Baumann and Prusak²³).

Table 9. Comparison of usefulness of learning activities used in senior level course Design for Manufacture in fulfillment of learning outcomes. The higher the number the higher the usefulness.

Codes for Learning Activities are in [Table 4](#).

Relationship code shown in [Table 5](#) was substituted for calculations with numbers:

● = 9 = strong, ○ = 3 = medium, Δ = 1 = weak, empty cell = 0 = negligible.

			Learning Activity																					
			Lect	Hw	Read	Quiz	Exam	Comp Lect	Lab Sh Exe	Lab Expm Team	Forens Indiv	Forens Team	Des Sh Exe Indiv	Des Sh Exe Team	Des Proj Indiv	Des Proj Team	Des Dev Lab Expm	Concept Gener	Critique	Info Search	Pres Indiv	Pres Team	Coop excell	Coop poor
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
			Level of emphasis in course																					
			●	Δ	●	Δ	●					○	Δ	○	Δ	●		●	Δ	●	●	○		
			Bloom's Taxonomy level																					
			1	2	1	1	2					4	3	3	5	6		5	5	3	3	3		
	Usefulness		522	80	594	42	495	0	0	0	0	378	34	93	91	1107	0	945	128	585	684	201	0	0
	Comparison of																							
	Learning Activities																							
	Used in Course																							

Conclusions

Design projects done in teams, concept generation, individual formal presentations, information search, compilation and reduction, as well as forensic studies proved to be the most universal activities, developing a wide range of professional skills. Future development plans for both courses envision inclusion of more forensic studies done in teams. That requires gathering of real samples since textbook and video examples almost always lack thorough investigation and follow through with improvement efforts.

Due to a variety of learning activities and assessment methods the two senior level courses described in this paper were chosen to provide assessment and evaluation data for continuous improvement efforts and for TAC of ABET accreditation self study and continuous improvement efforts in Manufacturing ET and Mechanical ET programs.

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