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DEVELOPING A DFX COURSE USING STRUCTURED METHODOLOGIES

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ABSTRACT

As part of the curriculum for a manufacturing program at Stanford, a Ph.D.-level course covering life-cycle design (also referred to as design for “X”) issues is required to be taken by students in the program. As a Ph.D. candidate doing research in this area, the first author (Martin) was asked to develop and teach this course. This paper discusses some of the issues in creating a new course and describes the use of structured methodologies (affinity diagrams, customer surveys, benchmarking, concept generation, and concept selection) in developing the course. Our goal in this paper is threefold: 1) to give an example of the use of structured methodologies in developing a course, 2) to show a sample curriculum for a dfX course, and 3) to present a framework describing course development.

KEYWORDS: Education, Life-Cycle Design, dfX, Structured Methodologies, Teaching, Course Development, Case Study

1. INTRODUCTION

In 1985 Professor Phil Barkan led a team of Stanford faculty in the development of a design for manufacturability (dfM) curriculum (this course was designated ME217 in the Stanford numbering system). This was in response to a request from industry for such a course. The team emphasized three fundamental issues in innovating a comprehensive graduate dfM curriculum: 1) definition of product competitiveness as related to features, life-cycle cost, and time to market, 2) emphasis on the early planning phase of product development, and 3) strategic integration of tools and methods throughout product development. In the past decade, the course has expanded into a six-month, project-based curriculum delivered to over 30 companies in four countries.

In 1990 Professor Barkan was asked to adapt his course for the Future Professors of Manufacturing (FPM) program. The FPM program is a Ph.D.-level interdisciplinary program designed to prepare individuals with industry experience for academic careers in manufacturing. They are admitted to either the Stanford business school or the engineering school and are required to fulfill all the obligations of their admitting schools. In addition, they take six Ph.D. courses and various seminars specifically tailored to manufacturing issues and current research in the field. The six courses are:

1) Manufacturing Systems Analysis
2) Manufacturing Performance Evaluation
3) Manufacturing Information and Coordination
4) Understanding Manufacturing Processes
5) Manufacturing Organizations
6) Life-Cycle Design (dfX)

These courses are taught on a rotating two-year cycle. The first two offerings of the dfX class (designated E613) were taught by Professor Barkan before his retirement. Following that, Professor Kos Ishii (the second author) taught the 1996 course. For the 1998 offering, the first author was asked to further develop and teach the course. The final description of the course is shown in Table 1.

Table 1: dfX course description (1998)

E613 will cover methods and research in the area of life-cycle design (also referred to as "design for X" or dfX). It is targeted towards Ph.D. students or those considering a Ph.D. The goals of the course are to: 1) introduce students to basic design methods such as quality function deployment (QFD), cost/worth analysis, design for assembly (DFA), failure modes and effects analysis (FMEA), concept generation/selection, robust design, etc.; and 2) discuss research issues in the area of life-cycle design. The course will be a mixture of information presentation and seminar discussion. A mini-project will have teams of three applying the current methods to the redesign of a single-use camera. Other assignments will focus on research issues. Enrollment will be limited to 15 students.

The process of developing the 1998 course began in the summer of 1997. Previous courses by Barkan and Ishii were used as guides, but the course was modified for two reasons. One was that the demographics of the students shifts dramatically from year to year. This is because the FPM students are older and have varied work experiences and also because of the various academic disciplines of the students. The other reason for modifying the course was that new research and new approaches to life-cycle design made a revision necessary.

Section 2 of this paper discusses the structured process used to develop the course. It also shows the syllabus resulting from this process. Section 3 describes a generic framework for course development. Section 4 briefly summarizes our work.

2. PROCESS TO DEVELOP COURSE

In developing a course, individual teachers have different ways of creating the syllabus and determining the assignments. They might follow the outline of an available textbook, use the syllabus from when they took the course, or they might just use their own intuition on how best to structure the course. We decided to try something different. Since the course covers structured methodologies in design, and since course development is a type of design, we felt it would be beneficial to use some of these methods to help develop the course.

The planned process involved various methodologies and is shown in Figure 1.

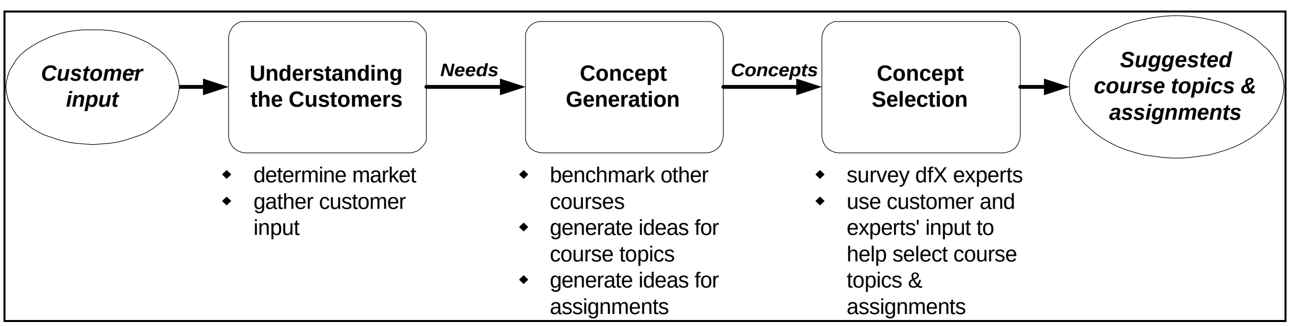

Figure 1: Process for development of dfX course

The process begins by gaining an understanding of the "customers" (i.e., students) by interviewing and surveying them (a discussion of other potential customers beyond the students is included in the next sub-section). Since the needs of the students can vary depending on such factors as previous work experience, planned career paths, previous classes taken, classes to be taken, etc., it is important to include a wide range of backgrounds in the people surveyed. This customer input is then used to help generate potential assignments and topics for the course. Then using concept selection methods, the process is used to select the course topics and assignments. A more detailed description of this process follows.

2.1 Understanding the customers

The target market for the dfX course is Ph.D. students who are interested in manufacturing and will enter academia upon graduating. Generally, academic careers revolve around the following four areas:

- research
- teaching
- service/community
- consulting

Using student input and the authors' own experience in academia, we generated a list of the needs of the students based around these four areas. While the main needs of the students are to learn and understand how dfX methods are used in design, we also discovered a desire to be able to apply certain structured methodologies (i.e., voice of the customer techniques, affinity diagram, and concept generation/selection) to help organize the students' research work. In order to gain quantitative information about the importance of these various needs, we generated a survey with the following questions (shown in Table 2).

Table 2: Customer survey questions for dfX class

How important is it for you as a professor of manufacturing to be able to:

Research

- relate dfX research directly to your own research?
- apply structured methods to help organize your research?

Teaching

- have a general knowledge about major dfX methods?
- teach dfX methods in your course?
- use structured methodologies to help organize your course?

Service

- utilize structured methodologies in your academic community work?

Consulting

- teach dfX methods in your consulting work?
- apply dfX methods to your consulting work?

The final form of the survey can be seen in Figure 2 on the following page. The quantitative results of this survey were later fed into the concept selection phase to help guide the choice of assignments and the topics to be taught.

E613 - Design for Manufacturing: Methods and Research

30-Sep-97

Name (optional) ________________________________ Major __________________

What do you think of when you hear "design for manufacturing (DFM) methods"?

What is your experience with design for manufacturing?

Academic Goals
Importance Questionnaire

How important to you is…	Points *
…academic community work (department committees, student society / project mentoring, etc.)	________
…consulting (working with outside companies / organizations)	________
…research	________
…teaching	________

* Divide 100 pts. among the four activities. More points implies a higher importance.

How important is it to be able to…	Not at all Important		Somewhat Important		Important		Very Important		Extremely Important	
	Please circle the number that represents your choice.									
...apply structured methods to help organize your research?	1	2	3	4	5	6	7	8	9	10
...relate DFM research directly to your own research?	1	2	3	4	5	6	7	8	9	10
…teach DFM methods in your classes?	1	2	3	4	5	6	7	8	9	10
…use structured methodologies to assist you in organizing your class?	1	2	3	4	5	6	7	8	9	10
…have a general knowledge about major DFM methods?	1	2	3	4	5	6	7	8	9	10
…apply DFM methods to your consulting work?	1	2	3	4	5	6	7	8	9	10
…teach DFM methods in your consulting work?	1	2	3	4	5	6	7	8	9	10
…utilize structured methods in your academic community work?	1	2	3	4	5	6	7	8	9	10

Figure 2: Final customer survey form

For our class, we had the benefit of knowing in advance which students were taking the course and because of this we could survey those individuals. However, even when this is not the case, a survey of a representative group of students would give useful information – especially for undergraduate classes, where the make-up of the class might be more stable from year to year.

For future courses, we will look at expanding the surveys to include other possible “customers". For instance, we could survey company managers or recent graduates to understand what the needs are for students going into industry. If a large majority of the students enter a particular industry sector (e.g., automotive or electronics manufacturing), we could focus more of our efforts on finding out how recent graduates utilize the course knowledge, and could tailor our teaching appropriately. We are not recommending sacrificing teaching the basic knowledge of the subject. For example, if you were teaching a heat transfer course, you should not skip teaching a student about Reynolds or Nusselt numbers to spend time teaching the software package that a particular industry uses. However, if there are opportunities to incorporate the needs of these other customers without compromising the fundamental aspects of the course, then those needs should be considered.

Just as in the design of a product, simply knowing the customer needs is not enough for the development of a useful course. These needs must be carried through to the details. The remaining sections of this paper describe the structured method we used to help guide us in doing this.

2.2 Developing ideas (concept generation)

Concept generation methods are used to break complex systems down into less complex elements and to generate solution concepts to satisfy those elements. There are various ways to sub-divide the complex system into more manageable elements. One method often used is morphological analysis (Pahl & Beitz, 1988). It uses functions as the less complex elements. Other methods use customer needs or the sequence of user actions for the dividing elements. For our concept generation process we used customer needs to sub-divide the system.

2.2.1 Concept generation for assignments

To help ensure the assignments we chose met the needs of the class, we utilized concept generation to develop candidates. The process consisted of listing out the customer needs and then brainstorming ideas for assignments which could help us meet that need.

For example, one need of the students was to “understand how dfX research relates to their own research”. Ideas that were brainstormed on how to meet this need were to “critique an ASME DETC *best* paper” (in order to understand what is considered good research in dfX), “search DETC papers and critique one related to their own research”, and “write a paper on the relation of dfX methods to their research”.

We generated possible assignments for all of the customer needs. An example for two of those needs is shown in Table 3.

Table 3: Example of concept generation for dfX assignments

Customer Need: **Understand how dfX research relates to their research** *Concepts*	*Customer Need:* **Help organize research, teaching, consulting** *Concepts*
Critique an ASME DETC "best" paper	Apply affinity diagram or concept selection to student’s research topic
Write a paper on relation of dfX methods to student’s research	Apply a structured methodology to student’s research topic
Do search on DETC papers and have student critique one related their research	Demonstrate to students the structured process used for E613 development

2.2.2 Concept generation for course topics

For the generation of course topics for E613, we relied on benchmarking and brainstorming to come up with ideas. Stanford has a well-established master’s level dfX course (ME217) and other universities such as MIT (Ulrich & Eppinger, 1994) and the University of Maryland (Magrab, 1997) have similar courses. Information from these helped us to generate potential topics for E613. A list of the generated topics is shown in Table 4.

Table 4: Concept generation for dfX topics

- Product definition
- Customer needs identification
- Function/structure diagram
- Quality Function Deployment (QFD)
- Affinity diagram
- Cost/worth analysis
- Design for Assembly (DFA)
- Failure Modes and Effects Analysis (FMEA)
- Poka-yoke
- Design for Serviceability
- Design for Environment (DFE)
- Concept generation/morphological analysis
- Concept selection
- Complexity in design
- Design for Variety (DFV)
- Design of Experiments (DOE)
- Taguchi methods
- Robust concept design
- Design theory and methodology

The selection process was then applied to help select the best assignments and topics for E613.

2.3 Choosing from the generated concepts (concept selection)

In concept selection the generated concepts are evaluated against a set of needs in order to determine the strongest ones. In our process, the assignments to be given the students and the topics to be covered in the course were the "concepts". We used the needs of the students as the criteria for evaluation.

To evaluate how well each potential assignment or topic satisfied the need, we gathered input from four people familiar with dfX methods and the student needs. These were the two authors, an ME Ph.D. candidate who was a former TA for ME217, and an industrial engineering professor familiar with the FPM program and the students.

Each assignment and topic was evaluated on how well it would satisfy the customer needs and how important the needs were to the students. A strong/moderate/weak (9/3/1) system of evaluation was used. A sample of the results of the concept selection for the topics is shown in Figure 3.

dfX Topics

Matrix: How well does method help achieve need?
9=strong 3=moderate 1=weak

	Customer Average Importance	QFD	Affinity diagrams	DFA	Concept generation	Concept selection: Pugh	DOE / Taguchi methods
Structured methods to help organize research	6	3	3		3	3	
Structured methods to help in organizing their class	6	3	3		3	3	
General knowledge about major DFM methods	7	9	1	3	3	9	3
Utilize structured methods in helping organize their academic community work	5	3	3		3	3	
Be aware of DFM research related to their own research *	6	3		1	1	3	1
Learn DFM methods related to the classes they will teach *	5	3		3	1	1	3
Learn DFM methods which can be applied to their consulting work *	5	3	1	1	3	9	3
Learn DFM methods which can be taught to industry audiences as part of their consulting work *	5	3		3	3	9	3
SumProduct		175	65	63	116	223	71
Ranking		2	5	6	3	1	4

* Evaluated these needs separately for each discipline (not shown here)

Figure 3: Example of concept selection showing top six dfX topics

For instance, in evaluating which topics to teach, QFD, affinity diagrams, concept generation, and concept selection were rated by the four participants as being moderately useful (a rating of 3) in helping the students meet the need of "structured methods to help organize research". These ratings were multiplied by the average customer importance to give a sumproduct score for each dfX topic. The average customer importance was derived from the customer surveys described previously.

Since there was a diverse group of disciplines (business school, industrial engineering, organizational behavior, mechanical engineering), we realized the usefulness of some of the topics would vary by discipline and we needed to account for that. Accordingly, we evaluated some of the needs separately for each discipline.

While not shown here, this concept selection process was also used to help determine the assignments for the course.

2.4 Application of process results

The concept selection weightings were used in deciding what to include in the syllabus, but the rankings were not blindly applied in making the decision. For instance, the function-structure diagram method was ranked relatively low. However, because it forms a foundation for other important methods such as concept generation, FMEA, etc. it was necessary to include it.

2.5 The output – a course syllabus

The end goal of the process was the development of a course syllabus that incorporated the needs of the students. The syllabus can be seen in Figure 4. It consists of 17 class periods which cover current dfX methods and research in the field. It contains two homework assignments, a paper, and a project. The assignments have the students apply structured methods (e.g., affinity

E613
dfX: Methods and Research

TOPIC	Week	Topic	Readings	Work	Notes
INTRO	1	Introduction to dfX	Pahl & Beitz - Chapter 1 U&E - Chapter 9		
METHODS	2	Customer Needs Identification	Concept Engineering U&E - Chapter 3		
		Quality Function Deployment (QFD)	HBR QFD article		
	3	*** No Class - MLK Day ***			
		QFD & Cost / Worth Analysis	ME217a Notes - Cost / Worth ME217a Notes - Producibility Poli et al articles		
	4	Function-Structure	Cross - Chapter 5	HW #1	Apply affinity diagram to research
		Concept Generation	Cross - Chapter 8		
	5	Concept Selection	Pugh - Chapter 14 U&E - Chapter 6		
		Design for Assembly (DFA)	Machine Design Handout ME217a Notes - DFA Barkan-Hinckley article		
	6	Failure Modes & Effects Analysis (FMEA) / Poka-Yoke	ME217a Notes - FMEA Poka-Yoke handout		
RESEARCH		Research in dfX	Kapoor-Kazmer paper Martin-Ishii paper	HW #2	Apply concept generation / selection to research
	7	*** No Class - President's Day ***			
		Robust Design Methods	ME217b Notes - Robust Design Ford paper		
	8	FMEA / Design for Serviceability	Eubanks et al paper Gershenson-Ishii article		
		Design for Environment	Eco-Indicator handout Hrinyak et al paper	Paper	Critique dfX research paper related to your field
	9	Design Theory and Methods	Sobek-Ward paper Horowitz-Maimon paper		
PROJECT		Project Presentations		Presentations	Redesign of Single-Use Cameras
	10	Project Presentations			
SUMMARY		Summary of Class		Project Report	Redesign of Single-Use Cameras

Figure 4: Course syllabus for dfX course

diagram, concept generation and selection) to their research objectives. For the paper the students critique a dfX research paper related to their field. The project involves the application of the methods to the redesign of a single-use camera.

The project accounts for 40% of the course grade, with the homework accounting for 20%, the paper 20%, and course participation 20%. Emphasis was placed on the project because we believe the application of the methods to a real product is one of the best ways to learn their strengths and weaknesses.

This ends the description of the structured process used to develop the E613 course (our first goal of this paper). It also gives a sample syllabus for a dfX course (the second goal of the paper). The third goal of the paper is to describe a framework that emerged for course development. This is discussed in the following section.

3. COURSE DEVELOPMENT FRAMEWORK

3.1 Issues in Developing a Course

Our original goal did not include the creation of a framework for course development. However, as we were going through the process of developing the course, the first author had numerous questions (this was his first effort at developing a course). Many of these questions were written down and are listed in Table 5.

The questions which arose during course development ranged from the philosophical ("what is the purpose of the class?") to logistical ("should I hand out my lecture slides in advance?"). While some of the questions are specific to the dfX course, most of them are generic and can be applied to any course.

3.2 Developing a framework using an affinity diagram

After the course syllabus was completed, it was decided to take these questions and see if any framework could be created which would help in future course development efforts

Listing the questions that arose during course development shows some of the complexities of designing a course. To gain a more thorough understanding of the higher-level issues of course development, an affinity diagram was constructed

Table 5: Questions arising during dfX course development

- How do you teach research in dfX?
- What is good research in dfX?
- What are the different aspects of life-cycle design?
- What articles do I use?
- What topics should be taught?
- How do I teach to a mixed target "market" (OIT vs. ME vs. OB students)?
- What should be the main focus of the students' time (project, paper, readings, assignments)?
- Do I teach general design theory and methodology methods?
- Should I make it a project course?
- How much reading do I give?
- Do I make the class a seminar-discussion or presentation format?
- Who are the customers?
- How do I translate the student needs into a structure for the course?
- Do I give a final?
- If I use a project, do I solicit different projects from companies, or do I give the students a project requiring no company interaction?
- How are the different methods actually utilized in industry?
- What teaching style do I use?
- How do I assess students?
- Do I bring in outside speakers?
- What does my audience want?
- What does my audience need?
- Do I hand out my lecture notes in advance?
- Do I use overheads or write on the board?

from these questions. Affinity diagrams are used to find underlying structure and relationships within unstructured qualitative information.

The process for the affinity diagram consists of taking the responses to a stated question and grouping them into logical groups. Following that, influences between the groupings are listed. For our effort, the overall question was:

"What are the issues in developing a dfX course?"

The "issues" came in the form of the questions shown in Table 5. The affinity diagram led to groupings and influence flows that gave a framework for course development. This framework is shown in Figure 5.

What are the issues in developing a dfX course?

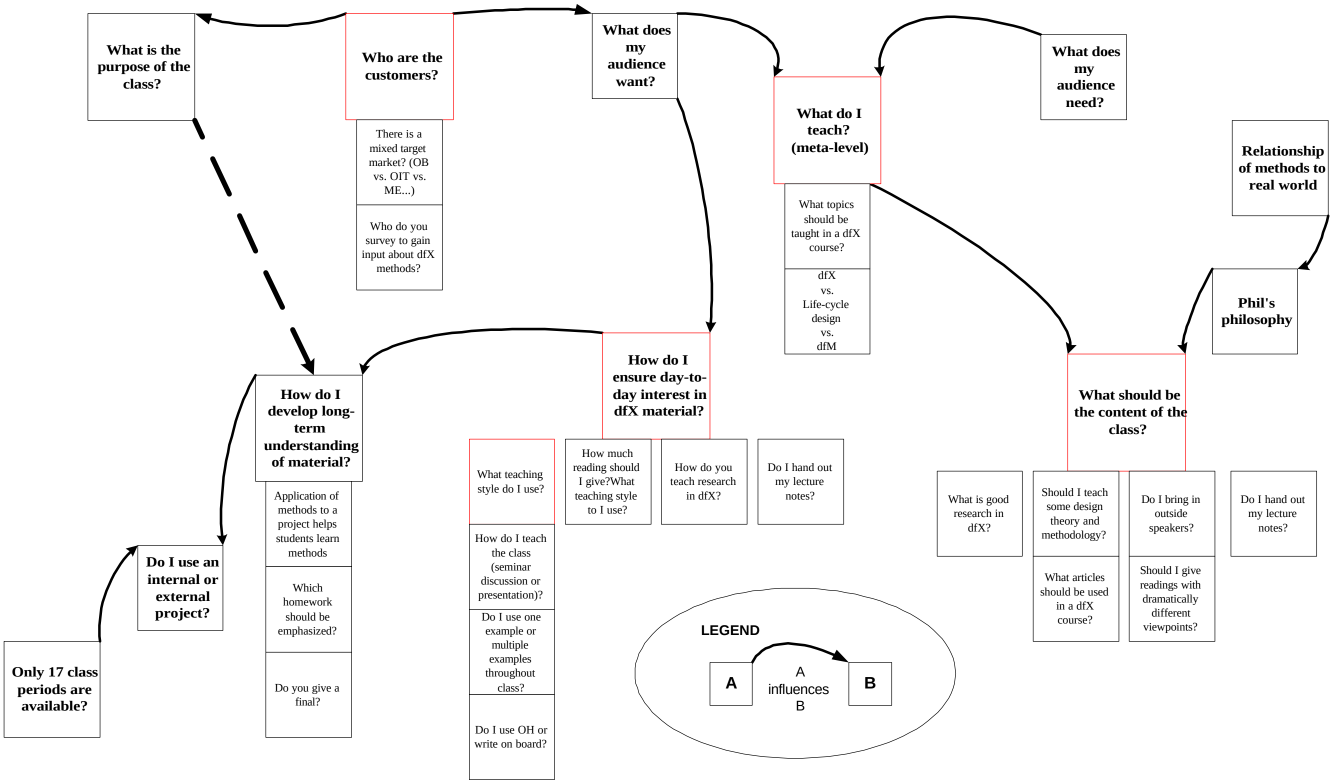

Figure 5: Framework for course development

The main question which arises in the framework is "what is the purpose of the class?" The diagram points out that the purpose of the class is influenced (shown by the arrow) by "who the customers are" which also influences "what your target audience wants are", etc.

The framework which emerged from the affinity diagram indicates the answer to the question of "what is the purpose of the class?" is to "develop long-term retention of material". While this statement might be considered obvious, the benefit comes from seeing the structure and influence relationships behind that answer. We plan on utilizing this framework to help us organize future development efforts.

4. SUMMARY

Developing a new course is not a simple task. Just as in the development of a product, there are many factors that determine the success of the course. Since our lab focuses on the development of structured methodologies for products, it seemed plausible that some of these methodologies might be useful in helping develop a successful course. From our standpoint, the use of these methodologies was very beneficial. The explicit results of using the process were ratings of the different topics and assignments to use for the course. In addition, the less tangible but equally important benefit was the better understanding of the students' needs. This not only helped in developing the content of the course, but also played a role in developing the daily lectures.

Student feedback on the use of the structured methods for developing the course was very positive – both at the start of the course and in the final course evaluations. Considering this feedback and our own experience using the methods, we plan to use this process to help develop future courses.

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