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Design & Development

of Biological, Chemical, Food and Pharmaceutical Products

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Preface

The twentieth century saw a huge expansion of the chemical industry – and of the career possibilities for industrial chemists and chemical engineers. For example, between 1950 and 1980 the number of cars in many western countries grew about one hundred times. And so did the industry delivering the fuels, lubricants, metals, polymers and paints required. Growth rates of 20% per year were not uncommon. This stopped around 1980 as markets saturated, and since then development in the bulk chemical industries has slowed down markedly as have the numbers of young graduates getting employed there.

Nowadays many chemical engineers are finding work in the development of new products. They work for a much more diverse set of industries – in which chemistry is usually only one of the disciplines that are important. You may find these engineers in electronics, in printing, in medical technology, in the food, car and cosmetic industries ... The skills required in such industries are quite different from those in the (rather sheltered) bulk chemical industry. Development is mostly done in multidisciplinary and multifunctional teams. Young engineers have to learn to work together in projects with people who speak different languages (both literally and metaphorically). Speed and a sense of urgency are more important than in the optimizing of bulk chemical processes. Team members are not only expected to be good engineers, but also to understand why cost, marketing and selling are important.

In this book we introduce major techniques used in designing and developing, roughly in the sequence in which they will be used. We show how techniques have been used (or could have been used) in a variety of products: a laundry detergent, insulated windows, toothpaste, anti-fouling paint, an insulin injector, a powder coating, a box of matches, herbicide capsules, foamed snacks, a pharmaceutical tablet, Rockwool insulation, a ballpoint and a methanol catalyst. The authors have been involved in the development of several of these products.

One can only learn to design and develop a product by doing it – not by reading a book. In our own courses about eighty percent of the time is devoted to project work – we give some examples. This is hard on both students and on us, because we have to follow what the students are doing without telling them what to do. We use the lessons for the other twenty percent: to introduce students to the techniques and to provide a framework for their projects. We hope that you will like them.

Groningen/Lyngby, January 2007
Hans Wesselingh (Johannes in Denmark),
Søren Kiil and Martin E. Vigild

Acknowledgments

This book has a long history. It is the result of two threads: one starting in Delft (and later Groningen) in The Netherlands, and the other in Lyngby in Denmark. Around 1980 at Delft University of Technology, the chemist H.C.A. van Beek† was having a hard time trying to get people to accept that large changes were coming in the chemical industry, and that they should be looking at higher-value (structured) products. He managed to convince a few of his colleagues, among them J.A. Wesselingh (JAW), L.P.B.M. Janssen (LJ) and H. van Bekkum. Together they put a curriculum together for students interested in what was then called 'product engineering'. In 1982 JAW and LJ started a course which gradually evolved into 'learn how a product works by doing experiments and setting up your own theories'. It was very successful.

In 1990 both LJ and JAW had changed universities. By coincidence they were working together in the small department of chemical engineering of Groningen where they continued their course, but otherwise were very busy with other things. In 1996 the board of the university – alarmed by the falling numbers of students in chemistry and chemical engineering – asked JAW to look at the possibility of setting up a study on product engineering. This was to be broader than engineering alone, and they suggested to do it together with people from the group of industrial pharmacy (N.W.F Kossen and later H.W. Frijlink) and to form a co-operation with the technically oriented people from the large department of business administration. The idea was supported by the deans of the Faculty of Sciences (P.C. van der Kruit and later D.A. Wiersma). JAW set up a number of projects in which teams of two to four masters' students worked a year on the development of some product, together with a local industry. The students were given a small budget and had to run their own project organization with help from industry and university. This was all very exciting, although it did conflict with the usual way of doing things in university. (The two big problems were that the university was not used to giving budget and project responsibility to students, and that development projects do not provide scientific research output.) JAW was retired in 2002, but his successor A.A. Broekhuis and R.M Voncken† have carried on the idea. The department has a healthy influx of students once again.

In Lyngby an initiative was started in the year 2000. The head of the chemical engineering department, K. Dam-Johansen, who had been working as a research manager in the paint industry, realised that product development was missing in the chemical engineering curriculum. He started several initiatives involving the young staff members S. Kiil (SK), G. Kontogeorgis (GK), J. Abildskov (JA), M.E. Vigild (MEV) and T. Johannessen (TJ). They were joined by JAW who spent large parts of 2003 and 2004 as a visiting professor in Lyngby.

The first and largest initiative was a 7th semester course called Chemical and Biochemical Product Design. It runs over three months, in which students are expected to spend 16 hours a week. The greater part is in projects which are done in teams of three to five students. In the last project students are to develop their own product (as far as possible in the limited time). This very ambitious course was first organised in 2002 by SZK, GK and JA. In 2003 and 2004 JAW organised a series of some twenty discussions with SZK, GK, JA, KDJ and MEV on how the subject should be structured and taught. With six people involved with different backgrounds (and large numbers of students interfering and contributing) these were hectic and emotional, but we learned greatly. What you see in this book is the course material as it has evolved over these last four years. It will keep on evolving (at least in the coming years), but we do have the feeling that we have found a suitable basic structure.

We have been greatly helped by young engineers from nearby Danish companies (Hempel – marine paints; Novo-Nordisk – insulin; Novozymes – industrial enzymes; Lundbeck – pharmaceuticals; and Coloplast – healthcare products). They gave guest lectures, commented on our ideas, and made it clear to students that this subject was one they were going to encounter in their careers. Some of their topics have found their way into the book. We have also had a lot of help and comment on the different examples by people who were involved at some time. These are acknowledged separately in the different lessons. Matthias Kind has provided us with a more general criticism. Bart Drinkenburg worked carefully through the whole manuscript and provided us with very useful comment and corrections. Then we must thank the hundreds of students that we have had on our courses. They have shaped our ideas with their many projects. The 2005 and 2006 groups have provided extensive comment and helped us to eliminate errors in the text. The staff of Wiley has converted the English of the Dutchman and two Danes into something readable and provided many other improvements. We must mention two other great helps: the books of Karl T. Ulrich and Steven D. Eppinger (*Product Design and Development*, McGraw Hill 1995, 2003) and E.L. Cussler and G.D. Moggridge (*Chemical Product Design*, Cambridge University Press 2001).

The three authors wish to thank their wives Trudi, Jette, and Éva for tolerating all the work outside office hours needed to put the book together. We would not have managed otherwise.

Introduction

Welcome to 'Design and Development'. In this course you are going to find out how new products are conceived, designed, developed, manufactured and sold – and how you may be involved in doing this.

This book is a text where *we* (the three authors) are saying something to *you* (as a member of a design team, so not to you as a single person). The book describes how we run our course – others may do this differently.

We warn you to expect something different from most other courses. You will be learning *how* to do something: how to design and develop a product. The emphasis is not on understanding how the product works (although it can be handy to know that). Here science is a tool, not an end. There are other things that you may find unfamiliar:

(1) After the introduction you will start doing things in teams – not alone.
(2) You are the ones who will have to find the answers, not we as your teachers. We do not know everything, but will try to help you. We are also learning.
(3) The problems are *open*: questions to which there is no single correct answer. You may not like the resulting uncertainty, unless you manage to see this type of work as adventure.
(4) Our course and this book are work in progress. We hope you will help us to improve them.

Projects

The core consists of four projects (Figure 0-1). We have given a few recent examples from our teaching under 'Projects': usually we change these every year. Four or five students work about forty hours each on the first three projects. The final project takes about eighty hours per person. Here each team is to design a new product of its own invention/desire/imagination/creation ... The time teams have available for the final project is perhaps one hundredth of that required for a full industrial development. So you will not be able to do everything perfectly and completely. However, we expect you to gain own working experience from this exercise and a feeling for what designing, developing and project work are like.

The first project uses lessons 1–4; the second, lessons 5–9; the third, lessons 10–15, and the fourth requires everything. Projects are done by teams of four or five students, and end with a presentation or a report.

The first three projects are *learning* projects only. You should try to master the subject; perfect results are not the aim. In the final project you are expected to consider all aspects of design and development and to *sell* your ideas.

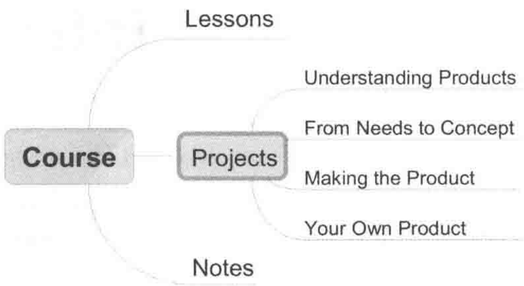


Figure 0-1 Position of the four projects

Lessons

In parallel with the projects is a series of some eighteen short lessons. We only show the four groups in Figure 0-2. The lessons give examples of product development, and introduce what you need to do. The titles of the lessons suggest activities that should be done in a well-defined sequence, but product development is more complicated than that. It is more like a cycle or set of cycles.

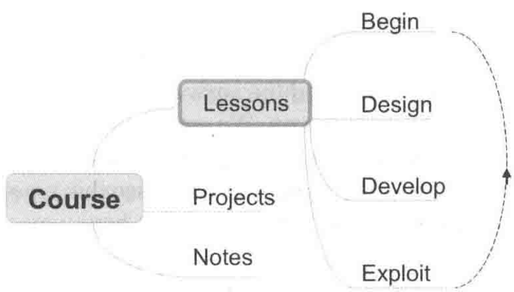


Figure 0-2 The four groups of lessons

Notes

There are notes on some of the many subjects that help you run your projects, but they are not central in the development sequence. Different notes may be relevant to different teams.

Colloids (with T. Johannessen)

There is a part of science that few of our students seem to have encountered, and that is important for the products that we have considered. That is Colloid Science (or Interfacial Engineering). These notes contain the minimum you need on this subject as a novice product developer.

Contents

continued on the next page

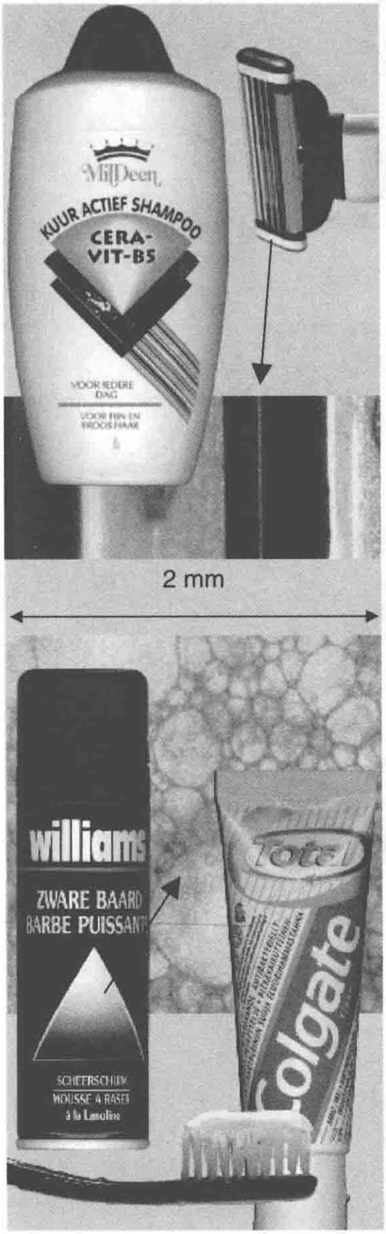
Lessons

Eighteen case studies and a conclusion. We hope these will give you a feeling for how products are designed and developed.

Part 1 Begin

New experiences can bring adventure, but also uncertainty and chaos. That applies to new product development just as well. These first four lessons will help you to get started, and to bring some order in the chaos.

Lesson 1: Look Around



To become a product developer, you must develop an interest in products. You must learn to look around, to find out how things work, and to find ways of improving them. We begin by walking around the house of one of the authors (JAW), which is nothing special. Here is what you see.

Products At Home

In the bathroom you find shampoo, a shaving razor with cream, toothbrushes with toothpaste, and a lot of cleaning agents. The shampoo is a translucent, viscous liquid: a concentrated solution of surfactants in water with thickeners, a pH-regulator and perfume. The razor, with three blades, is sharp. It is made such that the user cannot cut himself deeply. The new metal blades are straight and gleaming under the microscope. The edge is not visible; its radius is no more than a few micrometres. The blade is used with shaving cream: a stiff foam with bubbles of around a tenth of a millimetre. No way of improving these you might think. However, you would be surprised how much they have improved in the past 20 years.

The toothpaste is like a solid, but liquid when sheared. It stays on a toothbrush as a little white sausage. It contains a large fraction of fine solid particles, as you find out by diluting with water and vinegar, and letting the mixture settle. The particles (which are mildly abrasive) are smaller than 30 μm. How could you get toothpaste to be effective in the crevices between the teeth where it really is necessary?

The first thing you see in the kitchen is the coffee machine. The coffee is in the cupboard above it, in a vacuum pack of metal foil. It consists of ground

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particles of about a millimetre of roasted beans. Why not smaller, why not larger? The coffee machine is an intriguing apparatus with a vaporiser that pumps boiling water into a filter where the coffee is extracted. As an engineer you might like to get an understanding of it using two-phase flow theory. Coffee has been around for centuries. Even so, it is still being developed. The companies Philips and Douwe Egberts made the mistake of underestimating the market for their Senseo Crema system which makes coffee using capsules. Good coffee made more quickly than with this machine. The companies have had to refuse customers because of insufficient capacity. There are more ingredients for drinks in this cupboard, but you move on to the next one.

Here you find the pastes. Hazelnut paste is a dispersion of particles in a thick emulsion of two liquids, as is peanut butter. Jam is thickened by natural polymers. Soft cheese, butter and margarine are in the refrigerator; these are complicated structures of fat crystals, oil, water and many other components. All these pastes have a yield stress that is low enough to let them be spread by a knife, but not so low that they run off bread. Users do find the cold butter a bit stiff and the jam a bit thin. As a developer you might want to improve these things. Bread – a solid foam – is a surprising structure when looked at it closely. Fresh bread is often too soft to cut easily.

In the same cupboard you find powders: sugar, salt and powdered sugar. Here you can see a lot under the microscope: the one-millimetre crystals of sugar, the smaller salt crystals (surprisingly battered and not the nice cubes that textbooks would tell you) and the fine, ground particles of powdered sugar. The two coarse powders flow freely, but the powdered one is partly caked and agglomerated. It is also dusty; could that be improved? The package tells that it contains an anti-caking agent E554; you wonder what that is and whether you could not find something with a friendlier name.