PRODUCT EVOLUTION DIAGRAM; A SYSTEMATIC APPROACH USED IN EVOLUTIONARY PRODUCT DEVELOPMENT

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ABSTRACT
Students of Industrial Design Engineering are offered a course in Evolutionary Product Development (EPD) that provides design guidelines for a low-risk strategy in new product development. This design approach is based on the observation that products typically go through a series of phases after their initial introduction onto the market. When applying the EPD method, students have to analyse the development history of a product. It was observed that students have a difficulty describing the complexity of the development history of products. In addition, the course lacked embedding in prevailing theories from the field of Innovation Studies.
Using analytical concepts from Innovation Studies, the Product Evolution Diagram (PED) has been proposed as a systematic approach for analysing the development history of product families. This method uses two elements. First, a tree diagram similar to the family tree known from biology is used to map a product's development path. Second, a so-called PEST diagram is used to map the influences from the environment or ecosystem that affected the evolving product. A timeline reference connects the evolving artefact with the ecosystem. PED is an analytical concept complementary to the product phases theory that is used as a guideline in new product development. Results from the course revealed that the PED diagram is a valuable instrument as it helps to develop a comprehensive view of the evolutionary history of products.

Keywords: Design methodology, innovation, path dependence, evolution, product family tree

1 INTRODUCTION

Innovation is generally regarded as the key to advancement and economic prosperity. It is commonly agreed that radical, new innovations imply both a promise of potentially high returns and a substantial risk of failure and loss of money. In reality, most innovations or new products come about on the basis of incremental steps, a strategy that greatly reduces risk.
Evolutionary Product Development (EPD) is a design approach based on the observation that products typically go through a series of phases after their initial market introduction. Eger [1] defined six of these product phases or evolutionary steps. A course in EPD is offered to master students of Industrial Design Engineering. The learning objective of the course is to familiarize students with design guidelines for a low-risk strategy in new product development. Students have to analyse the development history of a product of choice in order to make a statement about the product's status quo or current 'evolutionary phase'. The theory of product phases then provides a framework of attributes for the (near) future version of the product. Students are asked to apply these guidelines when designing an evolutionary next version of the product in a follow-up course.
The theory of product phases focuses on relationships between 'design' (the looks) and the following aspects: functionality, ergonomics, production and marketing. It does not specifically analyse the technical characteristics in terms of performance increase, technology changes, standardization etc. The approach currently lacks a connection with prevailing theories from the field of Innovation Studies [2]. Moreover, it has transpired in education practice that students find it difficult to interpret technology transitions that are extremely relevant to their object of study. To fill this gap, a systematic approach has been proposed for analysing the product development history. This method results in a diagram referred to as the Product Evolution Diagram (PED). It systematically maps technology

transitions and changes in product architecture and relates them to influences from the environment (ecosystem) to provide a comprehensive picture of the evolutionary history. The PED has been used since 2011 in the EPD course as a complementary analytical tool to help students develop a better understanding of the product development history. Subsequently, it was assumed that a better understanding of the developmental history would contribute to the success rate of newly developed products. This paper explains the PED approach and provides some examples of work by students who applied it.

2 EVOLUTIONARY PRODUCT DEVELOPMENT

The EPD approach defines step-by-step product development or innovation strategies based on the product phases theory. The current 'phase' is defined by positioning the product according to a number of product characteristics. Each phase is defined by ten characteristics, of which four are product-related (newness, functionality, product development, styling), two are market-related (number of competitors, pricing) while four others are related to production, promotion, service and ethics. The six product phases are performance, optimisation, itemisation, segmentation, individualization and awareness. Initially the phases postulated were assumed to appear sequentially. A recent study [3] defined three sequential phases plus another three that appear to co-exist as a fourth phase as shown in Figure 1.

Figure 1. The six product phases

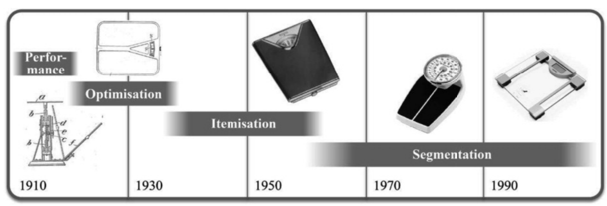

Figure 2. Visualization of development history of scales used in course 2010-2011 by Willem Sander Markerink

Students are asked to investigate the development history for a product of their choice and make a statement about the 'product phases' completed so far during the development. A table that lists ten product characteristics in rows and the six phases in columns is used to analyse the 'product phase evolution'. The table provides an overview of the extent to which the characteristics apply to the phases in terms of -, ±, + or? This table and its symbols is useful in research as it is easy to aggregate a number of different tables. The lack of visual appeal of this table is a drawback, especially for students Industrial Design Engineering. Before the PED was offered, students commonly used visualizations as shown in Figure 2 to map particular product embodiments through time in relation to the product phases. However, such visualizations do not capture the evolutionary trajectories nor the context.

Several efforts are being made to refine the product phases theory as well as EPD practice. One of these involves developing a diagnostic tool [4] that provides automated advice regarding products to be developed. Another, which is described in this paper, aims to develop a more coherent analytical framework that provides a better understanding of the evolution of products as well as to embed the EPD approach in the prevailing Innovation Studies theories.

3 TECHNOLOGICAL INNOVATION AS AN EVOLUTIONARY PROCESS

The ten characteristics identified in EPD are quite comprehensive. However, they do not systematically map the technology evolution trajectories that are so distinctive for evolving product families. In order to be able to describe the process of evolution in products or, more generally, artefacts, one needs to understand the cause and effect of changing technology as well as dependencies. The field of Innovation Studies provides concepts that help analyse and describe technological innovation. Embedding these concepts in the analytical part of EPD will lead to a more comprehensive understanding of how products developed over the course of history, how they relate to each other and what influenced their development. In other words, how they evolved.

The idea that the outcome of innovations depends on the path of development is a key concept used in Innovation Studies. One of the best-known examples of path dependence is the case of the QWERTY standard in keyboard layout. A frequently cited article [5] discusses QWERTY as being not the most efficient layout in terms of maximum possible typing speed. Nevertheless, the design became 'locked in' during the early days of mechanical typewriters. Once such a standard has been set and sufficient numbers of people use it, economies of scale propel it onwards and the standard becomes quasi-irreversible. Path dependence as an analytical perspective has also been used to explain the evolution of standards in video recording [6]. Both industry and academia are aware that once standards have been set, they shape the competitive landscape. Hence, standardisation remains a hot topic in innovation policy e.g. for high definition television, and operating systems for computers or mobile phones.

A second example of an analytical concept used in Innovation Studies describes innovation dynamics in terms of technological discontinuities and dominant designs. According to this theory introduced by Anderson and Tushman [7], an 'era of ferment' in which various technical designs compete for survival is started by a technological discontinuity. Subsequently, a dominant design emerges and heralds an 'era of incremental change' until the next discontinuity appears.

During EPD lectures it was observed that students have difficulty describing the complexity of the development history of products. In general, they are unfamiliar with the concepts used in Innovation Studies and consequently lack the insights to recognize and describe the development history. It appears to be difficult to indicate which factors from the macro-environment influenced product development history. The cause and effect of changing technologies, dependencies in the development path and essential milestones in the evolution of products or technologies are commonly overlooked. Consequently, students have lacked the insights and instruments to analyse and describe evolution trajectories.

4 PRODUCT EVOLUTION DIAGRAM

The EPD course contains three lectures of which one is dedicated to PED. The lecture uses several examples to explain how technologies and related products develop over time. The example of the telephone is used to illustrate how discontinuities in technology lead to new product designs. In the case of telephony, networks initially used operators to connect calls manually. This was sufficient for low numbers of connections. As a way of adapting to increasing use, pulse network technology was introduced which required telephones with a rotary dial, thereby rendering operators obsolete. This technology discontinuity also affected the design of the product (Figure 3). First, the rotary dial was added to the candlestick telephone. Then the cradle phone became the new dominant design, with the dial at its heart.

Figure 3. Early evolution in telephones

The Product Evolution Diagram, as shown in Figure 4, has been put forward as a means of providing a framework for analysing the development history of products. This method uses a diagram similar to the family tree used in biology to map the development path of the product family. In the product family tree, discontinuities in products or underlying technologies are represented by new branches in the tree. Products that cease to exist form dead ends.

The bottom half of the diagram depicting the 'artefact evolution' is referred to as the Product Family Tree. The upper half of the diagram depicts the 'ecosystem' and provides a systematic mapping of factors from the environment that influence the development of the artefact. A mnemonic commonly used in strategic management called PEST (Political, Economical, Social and Technological) is provided in order to analyse macro-environmental factors that influence development. Legal and Environmental factors are often included as well, causing the acronym to change to PESTLE.

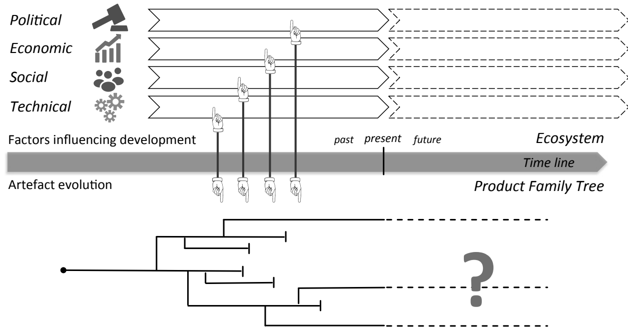

Figure 4. The Product Evolution Diagram

A timeline connects the artefact evolution with the ecosystem. As a whole, this diagram provides a comprehensive overview of the evolution of a product family. This makes it easier to understand where technical discontinuities set in and what influenced the development path, thereby leading to an understanding of why products evolved as they did. Adding new factors that are expected to influence future products (e.g. demographic changes, planned legislation or standards) provides a perspective on the current evolutionary forces.

Recognizing what technical discontinuities and context influences shaped product families contributes to an understanding of the product evolution. Hence, a clear view of current technological changes and context influences contributes to successful new product development.

5 HOW STUDENTS APPLY THE FRAMEWORK

In the EPD course students are asked to analyse the historical development of a product and record this in a PED. Four decades of the Consumentengids, the Dutch consumer guide, are made available as the main source of information. The guides provide comparative reviews including prices, test results and developments in product families available on the Dutch market at the time of publication. Several historic Sears catalogues providing information on products from the North American market are also made available. Together they form an 'archaeological archive' of consumer products. Students are not restricted to products reviewed in Consumentengids and at least two scientific publications have to be used in their analysis.

Figure 5 depicts a product family tree of the evolution of backpacks starting in around 1880. In the analysis it appears that technological progress in textiles, frame technology and lock-apparels (zippers, snap fits etc.) was instrumental to the origin of modern backpack designs. The diagram shows that, over time, the product family has become more complex. The use of backpacks increased and new designs evolved which were targeted at specific types of use (segmentation). The diagram in Figure 5 includes the product phases but excludes the ecosystem of influences. Technological development in the major components of backpacks is shown in an insert. Figure 6 depicts the evolution of steam irons. This diagram includes influential historical events from the ecosystem (such as the introduction of the new material Bakelite). Figures 5 and 6 both show how products refine over time and evolve into product families that cater to different types of use.

The PED framework was first applied in an article describing the evolution of Child Restraint Systems [8]. It again showed how, over time, an initial simple version of a product evolves into a refined family of products optimized for different types of use or market segments.

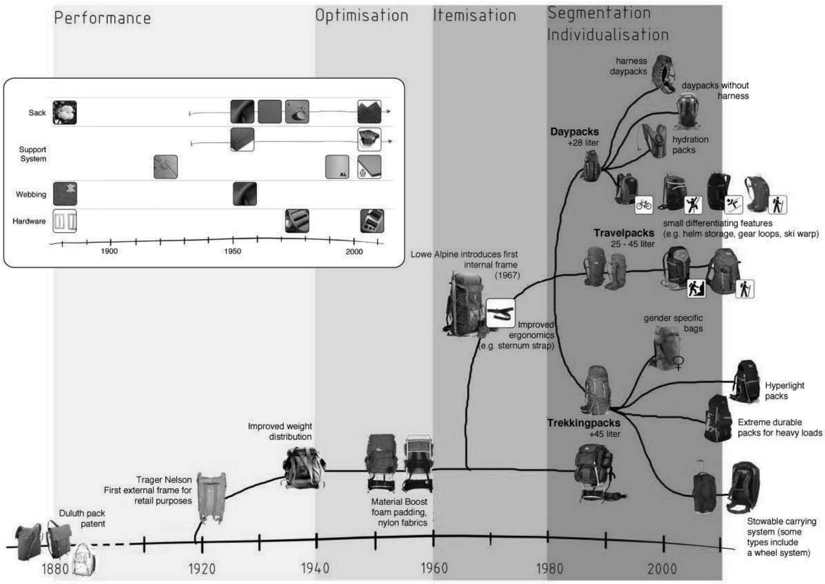

Figure 5. A Product Family Tree of Backpacks by Liesbeth Stam

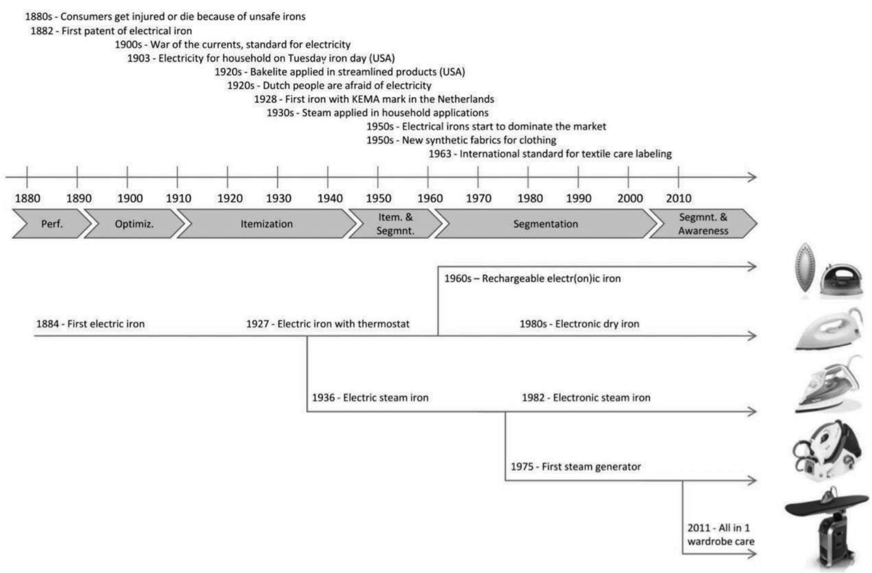

Figure 6. A Product Evolution Diagram of Steam Irons by Pieta van der Molen

6 EVALUATION

The EPD course that provides a study load of 5 European Credits was first to include a guest lecture on the PED framework in November 2011. Overall the course was rated ‘good’. The relevance of the course for preparing the students for their future professional career was rated excellent. Clearly the course is greatly appreciated.

Table 1 provides an overview of the results from the EPD course since the PED framework was used. Students’ work was graded on a ten-point scale (with ten as maximum performance and five or lower as a fail) by two supervisors and then averaged. For ease of interpretation the numerical grading has been divided here into three groups. In both the first and second year, a similar share of student work was rated excellent. In the first year one student failed and seven did not complete the course (for reasons not registered). In the second year no students failed and only one did not complete the course. Improvements in the second year lecture might have improved completion rates.

Table 1. Results of participation and evaluation of the EPD course

Results	Year 1 (2011-2012)		Year 2 (2012-2013)	
Excellent (8 or higher)	11	41%	12	39%
Moderate	15	56%	19	61%
Fail (5 or lower)	1	4%	0	0%
Course completed	27	79%	31	97%
Not completed	7	21%	1	3%
Total participants	34	100%	32	100%

The analytical framework provided helps students to analyse and visualize the evolution of products in terms of technology transitions and dependencies. Now students use PED they are demonstrating that they are able to provide a comprehensive overview of the evolution of products. This was something students were unable to do before PED was introduced as an analytical tool. However, improvements in quality of designs produced when using EPD incorporating PED have not been investigated so far, let alone an evaluation of market success of products actually entering the market.

All the students that completed the course in the years studied used a product family tree in their report. A substantial share did not use the prescribed analysis of the ecosystem in terms of a PEST diagram. However, other interesting alternatives, such as a mapping of the evolution of major components of the products, have been used several times.

7 CONCLUSION

Applying the Product Evolution Diagram generates a comprehensive view of product development history. First, a product family tree maps transitions in products and underlying technologies. Second, influential events from the ecosystem in which the development took place are mapped in a PEST diagram that is linked to the product family tree via a time line.

Results from an EPD course have shown that the Product Evolution Diagram as an analytical instrument helps to develop a systematic and comprehensive overview and thereby contributes to an understanding of the evolutionary history of products. The framework introduces prevailing theories from the field of Innovation Studies in a course for students of Industrial Design Engineering. The approach contributes to building the scientific foundations of design engineering education in general and the course in Evolutionary Product Development in particular.

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