AEDS 2007 WORKSHOP
26– 27 October 2007, Pilsen - Czech Republic

USE OF ESTIMATION AS A METHOD IN EARLY PHASES OF PRODUCT DEVELOPMENT

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Keywords: estimation, product development, method, engineering design

1. Introduction

1.1 Motivation

A great number of methods, methodologies, guidelines and tools can be found to support the product development process (PDP), e.g. [Pahl 2007], [Ullrich 1995], [Hubka 1992]. The information flow through more than 200 different methods and guidelines, which are currently used within the product development process, were analysed in order to create an all new methodology. This brought up some interesting aspects. Most methods are used only in the early phases of the PDP, while in the later phases the number is limited to a hand full of methods, which are mainly helpful on quality and calculating aspects. Among all analysed methods there was no useful support found for transforming principal sketches into engineering detail drawings and computer based data. This leads to the assumption that especially for low performance products a lot of estimation is involved in the PDP. Expert estimation, which is similar to the Delphi method, is mentioned in the VDI guideline 2221 [VDI1987]. But besides that, Lindemann [Lindemann 2005] was the only reference, which could be found proposing estimation as a method for systematic product development.

1.2 Objective

Bringing up estimation in context of product development shall raise the awareness of this method, which is probably often used unknowingly. By this it could be labelled as a useful method for product development. This should allow optimizing this method and the user's personal estimation abilities.

1.3 Methodology

A literature study will be used to examine the nature of estimation and its relevance for the PDP. Literature about estimating, which is not related to engineering design, will be put in a new context, so that relevant aspects can be used to support the PDP. A brief study will be carried out to investigate the estimating abilities of novice and experienced engineers in comparison to non-engineering control groups.

2. Estimation in product development

An estimate is a "judgement or calculation of the approximate size, cost, value, etc. of something" [Cowie 1989]. Many different ways of determining values by approximation are associated to the keyword estimation. That could be for example guessing, assuming, back-of-the-envelope calculating, extra- and interpolating or proceeding by a rule of thumb. Some of them could be part of participants processing in the brief study, some have intersections and several go beyond our scope.

2.1 The nature of Estimation

Estimation as a scientific topic is much more considered in psychology and neurology than in engineering design, cf. [Tylor1995], [Coben1995]. In tests like the Cognitive Estimation Test (CET) the focus is put on apperception and cognition. These tests are useful to examine the process of estimation itself and the general capability of probands to estimate neutral parameters, but they will not provide information about the specific characteristics of estimation in engineering design.

The process of estimation can consist of various subsets of the steps shown in Figure 1, depending on previous knowledge, apperception and estimation object.

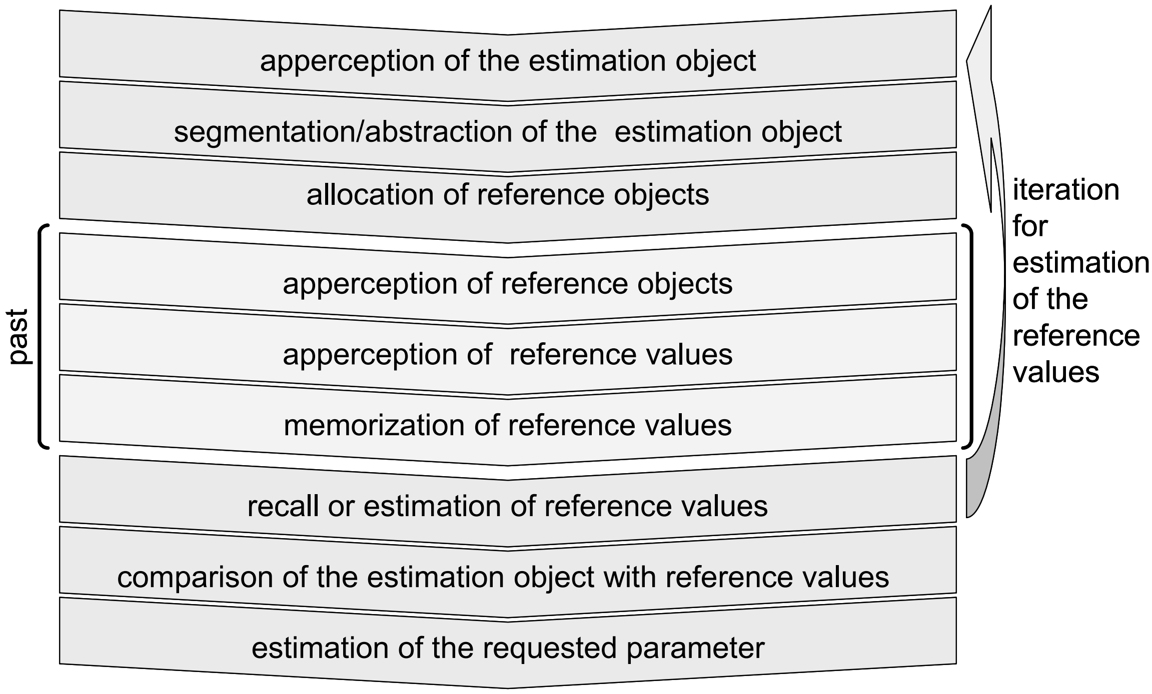

Figure 1. General estimation process

It has to be considered, that in some cases the estimation object is identical to the reference object. Whereas the acquaintance of the estimation object not necessarily results in the knowledge of the asked parameter.
Relevant ways of apperception, also influencing the performance of estimation, maybe in combination, are: visual - in original, as photography or in the form of text and numbers -, as well as haptic, by weighing masses per hand. Which type of apperception is most effective in respect of estimation, depends very much on the individual information processing of each test person.

Options for improvement of estimation performance by systematic proceeding like compartmentalization are the same as in product development described by Lindemann [Lindemann 2005]. They are stated in the following chapter.

2.2 Estimation as a method in product development

There is only very little evidence of estimation as a method in product development. VDI guideline 2221 [VDI1987] mentions the expert estimation as explained by Geschka and Reibnitz [Geschka 1981]. According to them estimates can be used as a fast methodical and intuitive evaluation method. Pre-formulated questions can help to improve the outcomes of this method. It is especially proposed for "badly structured" problems. It is not used in order to generate new information, but the results of other methods can be proven for plausibility.
Lindemann [Lindemann 2005] explains the estimation method in a slightly different way. According to him it is a useful method to fast generate the required information, when precise calculations, numerical simulations and physical test cannot be carried out due to high costs or complexity.

Estimates can be based on experience or on comparisons with similar objects. It is an engineering method and more than a "vague feeling" [Lindemann 2005].
Different ways to improve the estimates are recommended [Lindemann 2005]:

- Dividing the estimation task in better manageable smaller tasks may lead to better results.
- Estimates are better, if more people are involved. Knowledge and experience are necessary. In practice it is been proven useful, if specialists come together to work on one task.
- A combination of estimates and exact calculation will also lead to more precise outcomes. The more important factors should be calculated, while the less important ones can be estimated to accelerate the process.
- A fourth way to get better data out of the estimation method is using comparisons. Results will improve, when data of similar problems is used within the estimation process. In some cases similarity analyses have to be taken into account
- Experience in the pertained topic as well as in estimation as a method has a big influence on the estimates. If the estimation method is frequently used, the probability of getting better results is higher. But therefore the results of former estimations have to be compared with precise data in order to get a feedback on the quality of the estimates and thus have a higher learning effect.

Even though the estimation method is faster, cheaper and can be run with less effort than calculations or test it has several disadvantages [Lindemann 2005]:

- Estimates are less precise than calculations and tests.
- Recognized errors often cannot be used to improve the results of the estimation, in some extend it still remains a matter of "feeling".
- Results are related on the people performing the estimation. They sometimes cannot be reconstructed by other people.
- If the estimator is no longer available there is no continuity in the results.
- In short term it is impossible to learn estimation.

3. Test

Even though it is not popular to admit that estimating is a frequently used method in engineering design, it might be utilized by engineering designers quite often and partly without recognizing. Then engineering designers should be better than other people in estimating parameters of technical products. In order to verify this and the following hypotheses a test for measuring the estimating abilities was carried out:

H1: Engineering designers can estimate technical factors more precisely than other people
H2: Graduated engineers can estimate technical factors better than novices in engineering studies
H3: Having a technical understanding, but not being an engineer helps to estimate technical factors
H4: Medium sized factors are easier to estimate than exceptional small or large ones
H5: Less abstract factors (e.g. length) are easier to estimate than more abstract ones (e.g. power)

The test was accomplished by four groups with differing educational and/or professional background and experience. The first group was formed by 12 engineering design scientists (ED scientists) from the chair of engineering design and methodology, representing the graduated engineers. The second group consists of 11 people without technical background. In a second session we expanded the sample by a group of 12 engineering design students (ED students) standing at the beginning of their studies and as fourth group by 16 physicists , working at the TU Berlin as research associates.

Table 1. Test groups

group	description	members
engineering design scientists	engineering design chair members	12
non-technicians	human resources department	11
engineering design students	beginners in engineering studies	12
physicists	research associates in physical sciences	16

Each candidate had five minutes to estimate nine values scaled from small to big in the three categories length (wall thickness of a PET bottle, racing bicycle, air craft carrier), mass (pen, book, car) and power (electric toothbrush, electric oven, bus). The estimation objects were shown by photographs except pen and book, which could also be weight by hand.
The sample of items in the questionnaire regarded, that everyday or at least well known object were chosen, but the specific values asked for, were not common to the test persons mostly.

4. Results

For validation of the proposed hypotheses mean and standard deviation of the test results, normalized to the actual values, were generated.

The bars presenting the datasets belonging to the electrical toothbrush were cut off, because the bad estimation results would have prohibited an expedient depiction in a diagram.

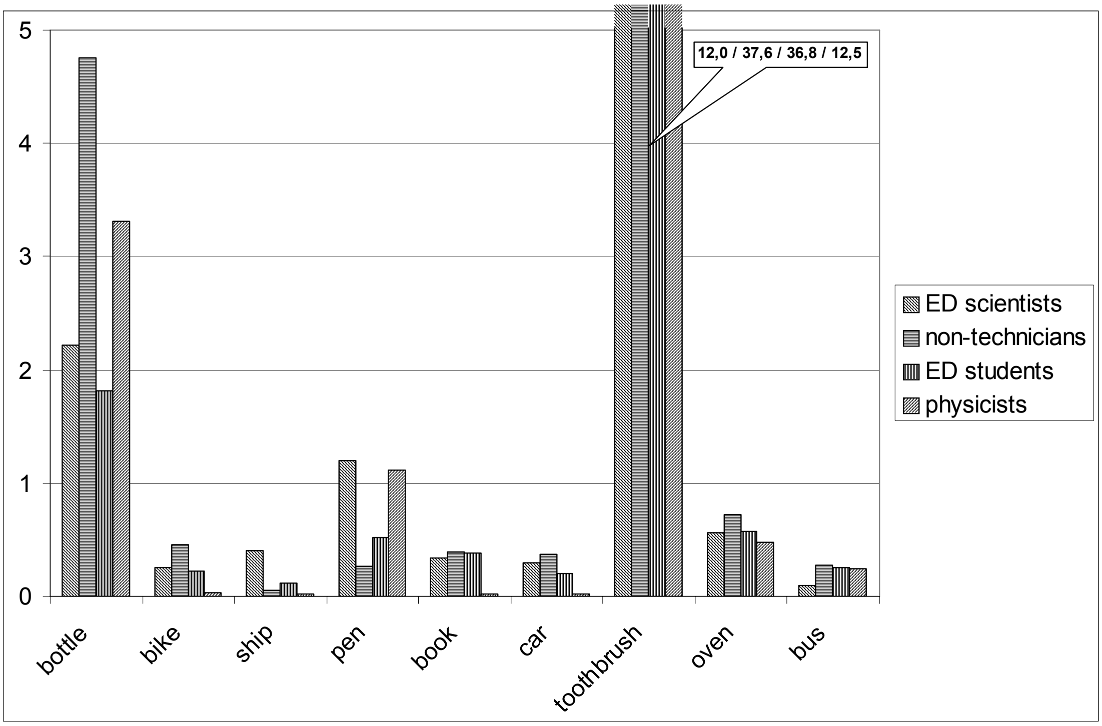

Figure 2. Comparison of absolute deviation to mean for normalized estimation results

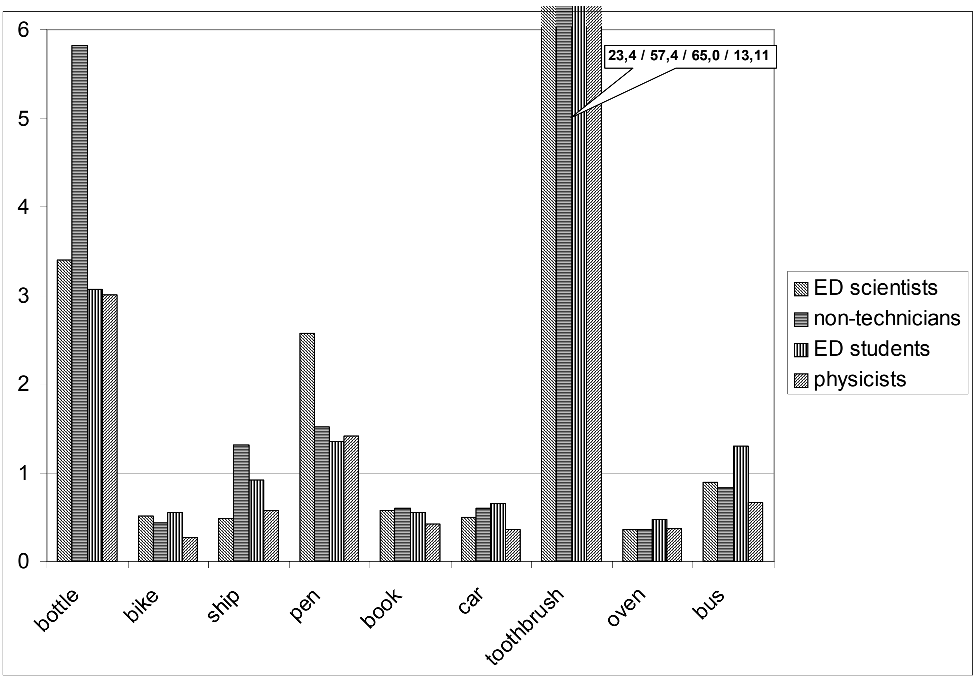

Figure 3. Comparison of standard deviation for normalized estimation results

The values of mean and standard deviation shown above were summarized for further aggregation of the findings. By averaging over mean and standard deviation pertaining to each of the nine estimation objects, a single value per test group was obtained.

Table 2. Ranking for average of estimation performance

group	mean	standard deviation
engineering design scientists	2	1
non-technicians	3	4
engineering design students	4	3
physicists	1	2

Auxiliary a rating test was used to gain singular classification figures per test group. For every estimation object a ranking was compiled, containing points from 1 to 4 according to the position. These points were summarized per group over the nine objects, which lead to a final rank for mean and standard deviation.

Table 3. Ranking of estimation performance rated per object

group	mean	standard deviation
engineering design scientists	2	2
non-technicians	4	3
engineering design students	2	4
physicists	1	1

It has to be annotated, that some test persons put in random values instead of guessing in case of total lack of knowledge of the asked parameter. In respect to this observed habit apparently nonsensical values were excluded retroactive to improve the explanatory power of the test results. Interesting in this context is, that the number of these wilful wrong estimation results given, correlates with the estimation abilities.

5. Discussion

The test design as used in our first approach is not perfect to extract detailed information about the influencing factors on estimation abilities, but gives a first idea of them.

The first hypothesis *(Engineering designers can estimate technical factors more precisely than other people)* can entirely be corroborated pertaining to the group with no technical relation. But in reference to the physicians, representing non-engineering but technical-related scientists, it is not approved. They accomplished roughly equivalent to the engineering scientists. The engineering students group is not fare better than the non-technical control group, what can be ascribed to the facts, that they are beginners.

Hypothesis 2 *(Experienced engineers can estimate technical factors better than novice ones)* is definitely admissible, because the engineering design scientists, representing ad least graduated engineers, performed far better than the novice engineering design students. So the engineering education seems to have a relevant effect on estimation ability, even without long-term professional practice.

Hypothesis 3 *(Having a technical understanding, but not being an engineer helps to estimate technical factors)* is true. The physical scientists as chosen test group for this aspect, did not only perform better than the non-technicians, but even matched with the engineering design scientists or rather overtook them.

Hypothesis 4 *(Medium sized factors are easier to estimate than exceptional small or large ones)* is approved, if asked parameters are not already known or very familiar to most test persons, like the mass of a middle-class car.

For the majority of the test persons the severity increases by the degree of abstraction of the demand parameters. That corroborates hypothesis 5 *(Less abstract factors (e.g. length) are easier to estimate than more abstract ones (e.g. power)*, if it is taken into account, that to many test persons the level of abstractness does not only increase from length, over mass to power. It also varies inside these categories due to the appearance of the estimation objects in every day life.

The validation of all of our hypotheses was not possible, due to the additional effects beside the educational and professional background like personal interests, intelligence in general, mathematical understanding, spatial sense, cultural and familial environment, etc., influencing the estimation ability in our test.

6. Conclusion

The intent of research presented in this paper and the related workshop is to create awareness for estimation as a serious procedure in certain phases of the product development process and its significance in engineering practice and accordingly education.
Although the test design was not appropriate for detail conclusions, we could already see that engineers have far better estimation abilities than non- technical educated persons. This finding leads to the question, how these abilities are gained and how this side effect of engineering education can be enforced and steered.
For further examinations a new test should be designed, which consists of neutral estimation objects, so the different influences on estimation abilities can be separated and more detailed conclusions about the influence of engineering education and practice can be drawn.
In addition a laboratory survey should be carried out, in which different groups are observed at solving basic engineering design problems, to gain detail understanding of the specific attributes of estimation in context of engineering design. Task and framework requirements have to be set in a way that test persons are forced to use estimation as a method to get a result. By this the examination of estimation abilities in coherency with engineering design could be enhanced and it should be possible to extract the differences between engineers and natural scientists of technical related disciplines (e.g. physicists), what was not attained by the attempt described in this paper.
Necessary would also be a comparison of engineering design scientists with long-term engineering design professionals with relevant practical experience. By this an evaluation could

be included, in which way the type and duration of work experience affects the estimation performance.
In either case larger test samples would be helpful to abate the impact of individual differences of the probands beside the influences according to engineering education and practice.

Acknowledgement

The work reported in this paper was partly financed by the Interdisciplinary Research Project (Interdisziplinärer Forschungsschwerpunkt IFS) 3/2 of the Technical University Berlin. The authors gratefully acknowledge this support and express their thanks.

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