INTERNATIONAL DESIGN CONFERENCE - DESIGN 2002
Dubrovnik, May 14 - 17, 2002.

TASK DESIGN AND TASK ANALYSIS FOR EMPIRICAL STUDIES INTO DESIGN ACTIVITY

Bernd Bender, Uwe Kammerer, Frank Pietzcker,
Lucienne Blessing and Winfried Hacker

Keywords: Empirical studies of design, methods in design science, research tools

1. Aims and Objectives

Many empirical studies into design activity have been undertaken in the last decade. In laboratory studies, design activity has been investigated by observing individual designers or design teams dealing with standardised design tasks. The results are valuable for a better understanding of design thinking and acting and for further development of design theory. However, there is a lack of comparability – and often of validity – of these studies (see e.g. [Cantamessa 2001], who investigated the publications of the ICED'97 and ICED'99 conferences with respect to these questions).
Our contribution focuses on the design and standardisation of design tasks to be used in laboratory studies and proposes a more systematic approach to task design in this area of research. Two concrete task designs are described, which have been applied and verified in an empirical study into the *applicability of design methodology in early phases of the product development process* ([Bender et. al. 2001b]).

2. The Aims of Tasks in Empirical Design Research

Although empirical research on design activity normally does not aim at testing individual design proficiency but rather at analysing design processes and design success, design tasks to be processed by participants in laboratory studies can be compared with tests such as those applied to psychological experiments or used for the assessment of job applicants: empirical studies into design activity can largely be categorised as combined tests of *personal characteristics* and *cognitive performance* ([Lienert & Raatz 1998], p.15). Therefore, considerations of test design and test analysis can be adapted for use in design research. The design of tasks for empirical design research has to ensure that the primary objectives of tests are met. These are ([Lienert & Raatz 1998], p.6)

1. in a cross-sectional approach:
   - to determine the status of an individual or a group concerning performance or personal characteristics or a combination of both;
   - to determine the differences between individuals or groups concerning performance, personal characteristics or a combination of both.
2. in a longitudinal approach:
   - to determine changes of performance or personal characteristics of individuals and groups within predefined periods of time.

It is a fundamental consideration of test theory (cp. the large discussion of *speed* vs. *power* resp. *time-limited* vs. *work-limited* testing [Lienert & Raatz 1998], pp.34 ff.), that test performance, processing time and the scope of test results are interdependent variables which cannot be reliably observed all three in one test at the same time - although in practice mixed tests often can be found. Test performance will always be the most important variable to be measured in real test practice, thus for increasing reliability of test results it is strongly recommended to measure either:

- the period of time needed by a test participant to reach a *predefined test result* (speed test) or
- the scope of test results achieved within a *predefined period of time* (power test).

3. Demands on Task Design for Empirical Design Studies

Appropriate design tasks have to meet some demands which are fundamental to tests ([Lienert & Raatz 1998], p.29ff.):

- objectivity, i.e. the inter-assessor reliability of the evaluation of test results:
  Test evaluation shall lead to the same results, when different persons evaluate the outcomes of the test. Therefore valid methods for the assessment of test performance have to be used ([Bender et. al. 2001a]).
- reliability, i.e. the reproducibility and internal consistency of the test results:
  A test has to be formulated in an unambiguous and clear way to ensure that the *same test person* being confronted with *the same test at a subsequent point in time* understands the test in the same way (re-test reliability), i.e., the test should lead to the same results. This is also true for the *same test person* being confronted with *different versions of one test* - i.e. applying the same test concept based on analogous test demands - *at the same time* (parallel-test reliability).
- validity, i.e. the perceptibility and predictability of personal and behavioural characteristics:
  For test validity, it is important that good test performance can be distinguished from poor test performance with sufficient certainty. Therefore, a design task has to be designed in a way that allows the formulation of precise and operational performance criteria. Ideally, a reference solution should exist. In addition, a test shall allow reliable conclusions regarding individual characteristics of the test persons to be drawn from measured test performance. The latter normally is not an issue when dealing with design tasks, if they are taken from design practice: the face validity of the task can be assumed.
- empirical relevance, i.e. the transferability of results from a “synthetic” laboratory situation to product development practice:
  Results of empirical design research shall not only be valid in a laboratory situation but also in product development practice. At the same time, however, the isolation of variables should be facilitated - which is easier in a synthetic environment - to increase objectivity and reliability of test results. As a consequence, a “synthetic” design task for a laboratory study has to be designed in such a way that adequate observation of variables is possible, while at the same time being as near to practice as possible for optimum transfer of results. This is also important for the acceptance of the experiment to the participants.
- adequate difficulty, i.e. the difficulty of the task should be suitable for the participants involved:
  The motivation of participants is very important in design experiments. A task therefore has to be designed that has adequate difficulty: not asking too much of the participants but also not being too trivial. The task shall be formulated in a way that enables the test persons to cope with the task
  - within the scheduled period of time;
  - with his or her individual qualifications (knowledge, faculty, skills);
  - with the provided resources.

The verification of this fundamental requirement for tests is subject to a pilot study. This is particularly relevant for test acceptance, because test persons often see their participation in an experiment as a test of their very personal faculty. The confrontation with a task that is experienced as unsolvable, which then results in poor test performance, might be interpreted as personal failure.

- efficiency, i.e. an appropriate balance of effort for and expected benefits from research:

Especially in empirical studies into design activity, test persons who come from industry often have

limited time available. In addition, the analysis of captured data is very complex. Test design has to make sure, that a sufficient number of potential test persons is expected to participate. Finally, it is very important to keep the expected amount of captured data manageable.
In conclusion, task design has to consider the same fundamental quality criteria as test design, with particular attention to objectivity, adequate difficulty and empirical relevance.

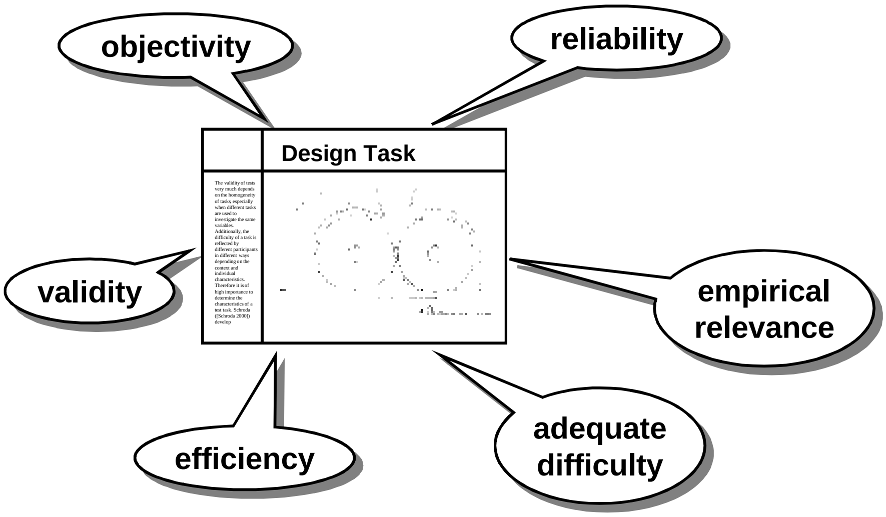


Figure 1. Fundamental demands on task design for empirical studies

4. Task Analysis and Standardisation of Design Tasks

Validity very much depends on the homogeneity of different tasks given to designers within a study. Homogeneity here can be defined as the degree of similarity of *different* tasks in measuring the *same* variables. A problem is that the difficulty of a task will be experienced differently by different participants depending on the context and individual characteristics. Therefore, it is very important to determine the characteristics of the tasks that are used. Schroda and Rückert ([Rückert et. al. 1997], [Schroda 2000]) developed and validated a taxonomy for the evaluation of design tasks to determine their suitability, which consists of six criteria:

- <u>conflicting aims</u>, determined by the overall number of aims, the number of conflicting aims, and the strength of the conflict;
- <u>complexity</u>, determined by the number of sub-functions, the number of relations between these, and the strength of the relation;
- <u>transparency</u>, determined by the availability of information on the initial status and boundary conditions;
- <u>degrees of freedom</u>, determined by the number of potential solution variants and solution paths;
- <u>dynamics</u>, determined by the variability of the initial status, the predictability of decisions and interventions, and external influences;
- <u>necessary knowledge</u>, determined by subject-specific knowledge, problem-adapted procedures, and common strategies for problem solution.

Based on this taxonomy, a questionnaire has been developed for analysis and categorisation of design tasks ([Schroda 2000]). Using this questionnaire, design tasks can be evaluated by different design experts. Subsequent testing of inter-assessor reliability of evaluation results increase validity and reliability. Thus, different design tasks can be standardised particularly with respect to the verification of homogeneity.

5. Task Design for the Conceptual Design Stage

Design tasks very much differ depending on the design stage to which they belong. Generally speaking, in the early conceptual design stage problems and tasks are often ill-defined and less restricted compared to problems and tasks of subsequent stages, such as the embodiment or even detail design stage. Design tasks for laboratory studies have to reproduce these specific characteristics from real design practice as good as possible to enhance the empirical relevance of the results of the study.

In design methodology, the transition from the stage of product planning to task clarification is determined by the formulation of a preliminary product definition – normally consisting of a description of the intended functions and a list of preliminary requirements, formulated in a solution neutral way ([Pahl & Beitz 1996], p. 128). These documents are "kick-off"-resources for the conceptual design phase, which shall lead to one or more principle solution variants. A solution neutral product definition and requirements list, therefore, have to be integral parts of a laboratory task as well. These might be formulated only verbally and briefly or comprise more detailed specifications requirement lists, depending on the research questions and hypothesis to be tested. This is important because [Fricke 1993] showed that the findings are different if you give less detailed task description compared to a more detailed one.

In addition, specific characteristics of the context in which conceptual design takes place should be reproduced in a laboratory environment by providing typical means for conceptualisation that are needed for the appropriate application of solution finding and evaluation methods and procedures (e.g. relevant literature, design catalogues, drawing tools for sketching, or, if applicable, materials for impromptu-modelling). In the case of group experiments, additional means for supporting discussion might be provided, such as e.g. a pinboard or flipchart. Figure 2 gives an example for an conceptual design task applied within a laboratory study into students' individual design heuristics [Bender et. al. 2001b].

Technical University of Berlin
Engineering Design & Methodology
DFG 479/68-1
Longitudinal Study, A2

No. of Participant: ____________

Conceptual Design Task

Finding, Varying, and Evaluating Solutions for a Shredder

Gardening is popular. During the gardening seasons a lot of yard trimmings, boughs, or loppings have to be disposed of. Here is a problem: Where to go with this "garbage"? A high-performance shredder offers an optimum solution. The volume will be reduced and the resulting shredded material is perfect for composting or mulching. The boughs and loppings are loaded manually and shredded by an appropriate mechanism. The chippings are ejected and collected in a bin.

The Task:

- At least three different concept variants for the shredding/ chopping of boughs and loppings shall be developed.
- The concept variants shall be visualised by sketches in such a way that the working principle and the geometrical arrangement of the relevant components can be identified.
- All concept variants shall additionally be shortly described and evaluated (e.g. function, relevant characteristics, advantages/ disadvantages)

Figure 2. Conceptual design task for a laboratory study into design heuristics

The measure of design success used in this stage is the quality of the delivered concept variants. We propose to evaluate this quality against the criteria *quantity*, *independence*, *transparency*, *function*, and *simplicity* of the concept variants, based on a value analysis approach [Bender et. al. 2001a]. In addition, for successful conclusion of the conceptual design phase and for subsequent use of its results, an evaluation of the quality of the concept variants, carried out and documented by the designer, is crucial. We therefore propose to include an explicit demand to the test persons to evaluate the resulting concept variants after finishing the conceptual design task. The quality of the documented evaluation of the concept variants is an important procedural evaluation criterion (see [Bender et. al. 2001b]) for identification of design success.

6. Task Design for the Embodiment Design Stage

The transition from the conceptual to the embodiment design stage is characterised by the development and selection of a principle solution. A good principle solution should contain ([Pahl & Beitz 1996], p.174):

- rough calculations;
- rough sketches;
- results of preliminary experiments or model tests;
- models (physical or by systems simulation);
- results of patent, literature and market searches.

These are the kick-off documents of the embodiment design stage which shall lead to the development of a preliminary as well as a definitive layout of the system. At least some of these documents have to be part of a laboratory embodiment design task. Figure 3. gives an example for an embodiment design task applied to the study mentioned above [Bender et. al. 2001b].

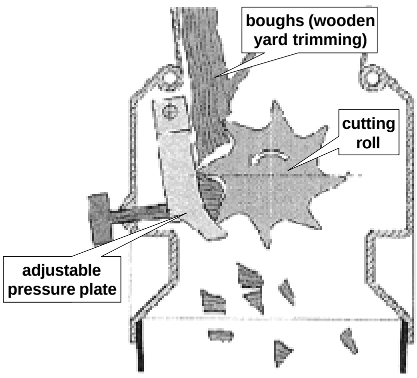
Technical University of Berlin
Engineering Design & Methodology
DFG 479/68-1
Longitudinal Study, A2

No. of Participant: _____________

Embodiment Design Task

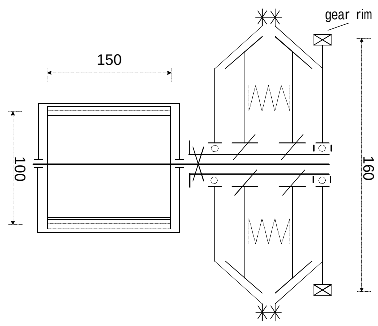
Embodiment Design of a Gardening Chopper

Designing a gardening chopper for hackling boughs and wooden yard trimming following the illustrated working principle is the topic of this embodiment design task:



Through an easy accessible funnel, wooden boughs are loaded to be hackled into pieces by a cutting roll. The cutting roll is driven by an electrical engine. Complying with safety issues, the chopper is equipped with a friction clutch to limit forces and torque.

An embodiment design for the cutting mechanism and the friction clutch shall be elaborated according to the following principle solution. The friction clutch is conceptualised as a double-cone cast design. Funnel and housing shall be shaped from steel plate. The adjustable pressure plate is not to part of this design task.



General specifications:

- compliance with principle solution and default specifications,
- friction clutch to be mounted on a stub chaft after DIN 748 40 x 110,
- dry clutch,
- the axial force shall be loaded by **one** coil spring,
- clutch sealed outwards,
- locating and non-locating bearing arrangement, all bearings with lubricating grease and separate gaskets,
- chopper housing out of steel plate, bearings in welded flange housings, screwed to chopper housing.

Layout specifications:

drive shaft ($\varnothing_{min}$)	40 mm
pitch circle-∅ of cutting roll	100 mm
width of cutting roll	150 mm
clutchdisc, outer ∅	180 mm
clutchdisc, inner ∅	150 mm
clutch disc cone angle	45°
coil spring (d x D x l_v)	6 mm x 120 mm x 50 mm
gear rim pitch circle-∅	160 mm
gear rim modulus m	4 mm

Figure 3. Embodiment design task for a laboratory study into design heuristics

Characteristics of the context in which embodiment design takes place are to be reproduced by providing means for the application of methods and procedures for the concretisation of solutions, the generation of geometries and for calculations (e.g. drawing tools, CAD-software, FEM-software, relevant literature, standards, catalogues etc.). Design success in this stage is determined by the quality of the elaborated embodiment design, documented at least by an assembly drawing and some embodiment determining layout calculations. Analogous to the conceptual stage, we propose a value analysis based evaluation against the criteria *function*, *layout*, *manufacturing*, *assembly*, *safety/*

reliability, *simplicity*, *clarity*, and *completeness* of the embodiment design [Bender et. al. 2001a].

7. Conclusion

For an appropriate task design, the aims and demands mentioned above have to be considered. Careful formulation of the tasks enhances the *objectivity*, *reliability*, *validity* and *empirical relevance* of the research. In addition, the adjustment of tasks to the qualifications and professional prerequisites of the test persons, leads to *adequate test difficulty* and therefore avoids stressful or trivial test situations. The application of the described method for task analysis and standardisation enhances task homogeneity. This is of particular interest for longitudinal studies to avoid distortion of results. If applied consistently, the comparability and reliability of design research in this area would improve significantly.

Acknowledgements

The authors wish to thank Dr.-Ing. Frauke Schroda and also Dr.-Ing. Carsten Rückert for developing the method for *categorizing engineering design problems* described in ([Rückert et. al. 1997], [Schroda 2000]) and testing this very effective instrument for the standardisation of experiments in their empirical studies into the *learnability and effectiveness of design methodology*.

References

[Bender et. al. 2001a] Bender, Bernd, Pietzcker, F., "A Guideline for Observation, Analysis and Interpretation of Design Procedures and Design Quality in Empirical Laboratory Studies", TUB-KTEM/ Technical Report 2001, Technical University of Berlin, Engineering Design and Methodology, 2001

[Bender et. al. 2001b] Bender, Bernd; Kammerer, U.; Pietzcker, F.; Blessing, L.T.M.; Hacker, W., "Successful Strategies for Complex Design in Early Phases of the Product Development Process, An empirical Study", in Culley, Steve et al. (Eds.): Proceedings of ICED'01, Glasgow UK: Design Research. Theories, Methodologies, and Product Modelling, Bury St Edmonds & London, 2001, pp.173-180.

[Cantamessa 2001] Cantamessa, M., "Design Research in Perspective – a Meta-Research upon ICED97 and ICED99", in: Culley, Steve et. al. (Eds.): Proceedings of ICED'01, Glasgow UK: Design Research. Theories, Methodologies, and Product Modelling, Bury St Edmonds & London, 2001, pp. 29-36.

[Fricke 1993] Fricke, G., „Konstruieren als flexibler Problemlöseprozeß. Empirische Untersuchung über erfolgreiche Strategien und methodische Vorgehensweisen beim Konstruieren". Düsseldorf, 1993.

[Lienert & Raatz 1998] Lienert, G. A.; Raatz, U., "Testaufbau und Testanalyse",6th Ed., Weinheim, 1998.

[Pahl & Beitz 1996] Pahl, G.; Beitz, W., "Engineering Design – A systematic Approach", 2nd rev. Ed., London, Berlin, Heidelberg, 1996.

[Rückert et. al. 1997] Rückert, C.; Giesa, H.-G.;Schroda, F.; Bender, Beate, "Categorizing Engineering Design Problems"Proceedings of International Conference on Engineering Design ICED'97, Tampere, 1997.

[Schroda 2000] Schroda, F., "Über das Ende wird am Anfang entschieden – Zur Analyse der Anforderungen von Konstruktionsaufträgen", Diss. TU Berlin, 2000, http://edocs.tu-berlin.de/diss/2000/schroda_frauke.htm.

[v.d. Weth 2001] von der Weth, R., "Management der Komplexität. Ressourcenorientiertes Handeln in der Praxis", Bern, 2001.

Dipl.-Ing. Bernd Bender
Technical University of Berlin, Dept. of Mechanical Engineering and Transport Systems, Engineering Design and Methodology,
Sekr. H 10, Strasse des 17. Juni 135, D-10623 Berlin, Germany
Tel.: ++4930 314-24309
Fax: ++4930 314-26481
E-mail: bernd.bender@ktem.tu-berlin.de