Stellingen

behorende bij het proefschrift van Henri H.C.M. Christiaans "Creativity in Design".

1 Indien het begrip creativiteit in de context van onderwijs en in die zin als een leerdoelstelling wordt gehanteerd, dan is een definitie van creativiteit in termen van een stabiele 'persoonlijkheidstrek' onbruikbaar. Een dergelijke persoonlijkheidstrek is immers per definitie onveranderbaar, waarmee aan genoemde doelstelling elke grond ontnomen wordt.
D.H. Feldman, 1980

2 Creativiteit meten lijkt alleen zinvol op basis van zichtbare en tastbare produkten. Een betrouwbare meting van produktcreativiteit is mogelijk op basis van de (subjectieve) oordelen van observators die bekend zijn met het domein in kwestie.

3 Het aantal genoten onderwijsjaren in een ontwerpopleiding, en dus het expertiseniveau, is niet voorspellend voor de mate waarin men in staat is creatief te ontwerpen.

4 Aan creativiteitstechnieken wordt voornamelijk waarde gehecht vanwege de hieraan toegedachte mogelijkheid om mentale blokkades weg te nemen en daarmee een ideeënstroom op gang te brengen. Maar zelfs die vermoedens zijn nauwelijks empirisch onderzocht.

5 De thans gehanteerde methodologie van het industrieel ontwerpen leunt te zwaar op die van het werktuigbouwkundig ontwerpen. Dit is weliswaar vanuit historisch oogpunt verklaarbaar, maar mag daarin geen rechtvaardiging vinden.

6 Van de soorten kennis die essentieel zijn in het ontwerpproces vertoont domeinonafhankelijke proceskennis, in termen van reflectie en controle, de hoogste correlatie met de uiteindelijke kwaliteit van het ontworpen produkt.

7 Het koppelen van het vakgebied der produktergonomie aan een technisch-universitaire opleiding heeft onvermijdelijk geleid tot een concentratie op objectief meetbare grootheden als lichaamsafmetingen en -krachten. Daarmee wordt tekort gedaan aan cognitieve aspecten bij produktgebruik.

8 Psychologen en psychiaters richten zich bij hun pogingen tot gedragsverandering teveel op de kwaliteit van de menselijke psyche en te weinig op de kwaliteit van de ontworpen omgeving van het individu.

9 Zitpijn op de fiets, waarvan circa één miljoen fietsers in Nederland last heeft, wordt zelfs door Van Dale ten onrechte aangeduid als "zadelpijn".
C.M.J. van Hulten en H.H.C.M. Christiaans, 1992

10 Muzikale vorming is wezenlijk in de opvoeding van het kind.

11 Het zogenaamde wereldkampioenschap schaken tussen Bobby Fischer en Boris Spasski, gespeeld in Joegoslavië en gesponsord door een wapenhandelaar, is wel een uiterst wrang voorbeeld van de overeenkomst tussen schaken en oorlogje spelen.

Creativity in design

Creativity in design

The role of domain knowledge in designing

Proefschrift

ter verkrijging van de graad van
doctor in de Technische Wetenschappen
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus,
prof. drs. P.A. Schenck,
in het openbaar te verdedigen ten
overstaan van een commissie aangewezen
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door

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geboren te Haarlem op 22 januari 1947
psycholoog

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Contents

Preface

Theory is the ultimate aim of science. In this book a research project is described which tries to contribute to this general aim. The focus of attention is on the domain of industrial design engineering, the world of consumer products. Although engineering is mainly an applied discipline it also needs a theory on which to base its methods. Over the last ten years I was in the fortunate position to investigate the creative activity of the designer. And I like to say that it was fascinating to work in a field where science and art, or systematic methods and creativity, are so deeply intermingled. It was just at these crossroads that the studies were conducted, aiming at the improvement of design methods for practical application: the development of design tools and design education. Especially the education side is at issue in the studies described here.
Research in industrial design methodology is still in its infancy. Although there are a lot of empirical studies in adjacent domains like architecture and mechanical engineering, most of the findings are not applicable to the typical industrial design domain. Because we are in a 'pre-theory' stage, as Dixon (1989) states, studies have still a explorative character. My job was to add systematized information to the already existing body of knowledge and to derive hypotheses from it. The basic assumption in my studies is that creativity is the most salient criterion of design. Hence, in order to evaluate the influence of knowledge applied and methods used during the design process the creativity of the result of this process, the ideas generated and the concept chosen, should be used as the criterion. That is the reason why this book begins with an extensive study into the possibility of creativity measurement. In the subsequent sections the design process is analysed from a cognitive point of view: what information and knowledge is processed during designing? And is there any relationship between this cognitive activity and the creativity of the design result? These issues are explored through empirical studies.

A research project is always a cooperative enterprise. Among the many persons who contributed to this book I am most indebted to those mentioned below.

Professor Wim Vaags encouraged me to study the creativity of designers. As the Dutch expert with respect to creativity research he helped me from the start of the project until last year. In 1991 he died. His contribution was invaluable.
Professor Jan Vastenhouw accompanied the project from start to finish. He helped me immeasurably with all problem which raised on the way. He read the whole manuscript and

made many valuable and constructive suggestions for improvement.
Professor Nigel Cross who half-way the project was willing to supervise the research activities. He also read and criticized the manuscript and made many valuable suggestions. I here express my admiration as well as my thanks to all three.
Two other people were very helpful during some parts of the project. Kees Venselaar and Kees Dorst, who were involved in this research project, discussed with me the theoretical implications and conducted part of the empirical studies. It was very stimulating to work with them both.
I like to thank the people who contributed to this book by means of their support and discussions: Henk Arisz and Mark de Hoogh (data analysis), professor Bernd Schierbeek, professor Dave Ullman, Kees Kornmann, Frits van Santen, Klaas Huizenga, Jenni Miller and last but not least Pauline Christiaans-Bakker.
Finally, many design teachers and students from the School of Industrial Design Engineering at Delft University were willing to cooperate in the studies. Thanks to them all.

Henri Christiaans

Bloemendaal
November 1992

Summary

The general aim of this study is to extend jointly the scientific base of design methodology and educational design principles within the domain of industrial design engineering. The study was conducted at the School of Industrial Design Engineering at Delft University in The Netherlands.
Although there is an increasing number of studies in adjacent design domains, such as architecture and mechanical engineering, design theory is still believed to be in its infancy. Educational principles and methods are mainly derived from prescriptive models in design which still lack scientific and sometimes practical foundation.
In order to contribute to industrial design theory and education the design process was explored from a cognitive viewpoint; i.e. designing was defined as an information processing activity. It was questioned what role domain knowledge plays in design and what kind of expertise is decisive to performance quality. One of the most important criteria for this performance quality in design seems to be the creativity of the design. Being novel and innovative is by definition a feature of design. Therefore, several studies were conducted as an attempt to operationally define creativity and to find a reliable measuring instrument. An assessment technique based on the consensus of judges, who are familiar with the design domain, was adopted. The results of several studies here demonstrate that product creativity can be measured reliably. This finding provided a criterion to be used in studies regarding the design process. In the same study the validity question was further analysed.

In studying the role of domain knowledge in relation to design creativity the use of rigorous research methods and experimental designs is almost impossible. In order to investigate the utility of methods two different elicitation and analysis techniques were tested.
The first method was based on the analysis of *retrospective* knowledge reports from first-year design students. Following that, a protocol study was conducted in which students with different levels of expertise solved a design problem while 'thinking aloud'; these *concurrent* data were analysed.
Regarding the first method, in a semi-longitudinal study the 'learner reports' of a number of design students were gathered over a year. In the reports students express what they'd learnt through the project ("I learnt that.."; I learnt how.."). These learner reports, written during and after the four design projects in the first year, were part of the students formal courses, i.e. not introduced for the sake of the experiment.
The analysis of the elicited knowledge was based on a classification of knowledge categories,

derived from the relevant literature. This classification had two overall dimensions; the first one was based on the distinction between domain-specific basic academic knowledge and design knowledge on the one hand, and domain-independent general process knowledge on the other. The second dimension was mainly based on the distinction between declarative and procedural knowledge, supplemented by two other categories, knowledge of situations and strategic knowledge.
The results regarding the research method used, demonstrate that the encoding system together with the coded material (the learner reports) gave too much room for confusion. As a consequence, reliable conclusions could only be drawn with regard to a combination of knowledge categories into more general dimensions. These conclusions are, firstly, that most learning experiences were classified as declarative knowledge. In accordance with many other studies, procedural knowledge as well as knowledge about situations and strategies seems difficult to elicit. A second finding is that during the year students concentrated more and more on the learning of domain-independent process knowledge, while domain-specific basic knowledge was mentioned less frequently. Thirdly, the creativity of the designs appeared to be related to the amount of process knowledge elicited. A trend was observed; subjects whose designs were rated higher regarding creativity, on average, reported a higher amount of general process knowledge.
In a protocol study this relationship was again studied together with the influence of different levels of expertise, defined by schooling grade (2nd-years = novices versus final years = intermediates) and performance level in the formal design courses. The data from the experiment show that, in the first place, no positive correlation was found between these two measures of expertise and the creativity of the design solutions. However, there were differences between subjects influenced primarily through design expertise. A quantitative difference was found regarding the external information used by novices and intermediates, the latter requesting much more information. Most novices showed a solution-oriented approach and worked backwards from the goal. They reduced the problem soon after receiving the brief to simply a redesign of the existing product, performing the task at their own level of competence. Information was scarcely sought, nor was much knowledge activated, and they broke the problem down into subproblems, solving these individual subproblems first before returning to an integrated solution. In general they handled the problem situation according to a 'generate and test' strategy.
Intermediates in general showed a problem-oriented approach. Although strategies such as logical reasoning seems irrelevant in design, most intermediates seemingly displayed a kind of forward reasoning. They tried to supplement their own knowledge with a considerable amount of external information. However, half of them failed to assimilate and integrate the information requested into an elaborate problem representation.
Nevertheless, the novice expert paradigm is not valid for explaining or predicting differences in product creativity. The way in which a knowledge structure is built through developing a 'macrostructure' for solving the problem seems decisive. Indications for this speculative conclusion were found in a number of data.
Finally, the educational implications derived from this study are attended to.

Future research should again focus on the development of the designers knowledge base. Solving ill-defined design problems asks for a domain-specific approach which in some respects differs from approaches in other domains. The study here showed that through involving the creativity of the design solution the data were able to be examined in a new light.

Samenvatting

De algemene doelstelling van deze studie is een bijdrage te leveren aan de ontwikkeling van een ontwerptheorie en afgeleide onderwijsmethoden voor het domein van het industrieel ontwerpen. Het onderzoek werd verricht bij de faculteit Industrieel Ontwerpen van de Technische Universiteit Delft.
Ondanks het toenemend aantal studies in verwante ontwerpdomeinen, zoals de architectuur en de werktuigbouwkunde, staat de 'industrial design' theorie nog in haar kinderschoenen. De bestaande technieken en onderwijsmethoden zijn gebaseerd op prescriptieve modellen die een wetenschappelijke en zelfs vaak een praktische onderbouwing ontberen.
Als bijdrage aan de ontwerptheorie en het ontwerponderwijs werd exploratief onderzoek gedaan vanuit een cognitieve benadering; dat wil zeggen het ontwerpproces werd opgevat als een informatieverwerkend proces, met als belangrijkste vragen daarbij: welke rol speelt kennis in het ontwerpproces en wat voor expertise is doorslaggevend voor het leveren van een kwalitatief goed ontwerp. Een van de belangrijkste criteria voor ontwerpkwaliteit is in de opinie van de auteur de creativiteit van het ontwerp. Per definitie dient een ontwerp nieuw en innovatief te zijn
Derhalve werden enkele empirische studies verricht in een poging om creativiteit operationeel te definiëren en een betrouwbaar meetinstrument daarvoor te vinden. Daartoe werd een bestaande beoordelingsmethode gehanteerd, die gebaseerd is op onderlinge overeenstemming tussen beoordelaars. De eis aan beoordelaars is dat ze vertrouwd zijn met het domein in kwestie. De resultaten van een aantal onderzoeken, die hier zijn uitgevoerd, laten zien dat het mogelijk is produkt-creativiteit betrouwbaar te meten. Dit resultaat gaf de mogelijkheid om creativiteit als criterium te hanteren bij de vervolgstudies naar het ontwerpproces. In dezelfde onderzoeken werd tevens de validiteit van het meetinstrument aan een nadere beschouwing onderworpen.

Voor een onderzoek naar de relatie tussen domeinkennis en creativiteit van het ontwerp zijn nauwelijks krachtige onderzoekmethoden voorhanden. Teneinde de bruikbaarheid van methoden te onderzoeken werden twee 'elicitatie'-technieken getest alsmede twee analysemethoden. De eerste methode was gebaseerd op een analyse van *retrospectieve* kennisrapportages van eerstejaars ontwerpstudenten. Vervolgens werd een protocolstudie uitgevoerd waarin studenten met verschillend expertiseniveau hardop denkend een ontwerpprobleem oplosten. Deze protocollen werden vervolgens geanalyseerd op basis van kenniscomponenten in relatie tot produktcreativiteit.

Wat de eerste methode betreft, tweemaal gedurende het eerste studiejaar werden de 'learner reports' van een aantal ontwerpstudenten bijeengebracht. In deze rapporten gaven studenten aan wat zij tijdens een bepaalde ontwerpoefening hadden geleerd ("Ik heb geleerd dat..." of "Ik heb geleerd hoe..."). Het schrijven van leerervaringen tijdens en na de vier ontwerpoefeningen in het eerste jaar vormde onderdeel van het reguliere programma en was niet als zodanig geïntroduceerd als onderdeel van het experiment.
Analyse van de aldus geuite kennis was gebaseerd op een classificatie van kenniscategorieën, ontleend aan de literatuur op dit gebied. Deze classificatie kende twee dimensies; de eerste was gebaseerd op het onderscheid tussen enerzijds domein-specifieke academische basiskennis en ontwerpkennis en anderzijds domein-onafhankelijke algemene proceskennis. De tweede dimensie was voornamelijk gebaseerd op het onderscheid tussen declaratieve en procedurele kennis, aangevuld met de categorieën 'kennis van situaties' en strategische kennis.
De resultaten ten aanzien van het instrumentgebruik laten zien dat zowel het codeersysteem als het gecodeerde materiaal (de leerervaringen) te veel ruimte gaven voor verwarring, met als gevolg dat slechts bij een grove indeling van kenniscategorieën betrouwbare conclusies mogelijk waren. De belangrijkste conclusies zijn in de eerste plaats dat de meeste leerervaringen gecodeerd werden als declaratieve kennis. Overeenkomstig vele andere studies op dit gebied lijkt het uiten van procedurele, situationele en strategische kennis veel moeilijker te gaan. In de tweede plaats kwam naar voren dat studenten tijdens hun eerste jaar meer en meer domeinonafhankelijke proceskennis uitten terwijl het aantal leerervaringen met betrekking tot domeinspecifieke basiskennis afnam. In de derde plaats lijkt de ontwerpcreativiteit gerelateerd te zijn aan de hoeveelheid proceskennis. In het onderzoek binnen twee afzonderlijke jaren is er een trend in dezen waarneembaar: studenten van wie het ontwerp als hoog creatief was beoordeeld, rapporteerden gemiddeld meer algemene proceskennis.

Deze relatie was opnieuw onderwerp van onderzoek in een protocolstudie. Tevens werd in dit exploratief onderzoek de invloed nagegaan van expertiseniveau, dat op twee manieren werd gedefinieerd: 1) op basis van het aantal doorlopen studiejaren (2ejaars = novieten versus 5ejaars = 'intermediates') en 2) op basis van de prestaties in het formele ontwerponderwijs gedurende de voorgaande jaren.
De resultaten laten in de eerste plaats zien, dat er geen positieve correlatie bestaat tussen expertiseniveau en de creativiteit van de ontwerpoplossing in het experiment. Niettemin zijn er verschillen tussen proefpersonen, juist op basis van expertise. Zo is er een kwantitatief verschil ten aanzien van de hoeveelheid externe informatie die tijdens het ontwerpen werd gebruikt, waarbij door 'intermediates' veel meer informatie werd opgevraagd. De meeste novieten hadden een oplossingsgerichte benadering en werkten vanuit het doel terug naar de oplossing ('working-backwards'). Zij brachten al snel het probleem uit de opgave terug tot slechts een herontwerp van het bestaande produkt, aldus de taak uitvoerend op hun eigen competentieniveau. Naar informatie werd nauwelijks gezocht, terwijl veel eigen kennis niet geactiveerd werd. Bovendien ontleedden zij het probleem in elementen en zochten zij oplossingen hiervoor, voordat zij terugkeerden naar een geïntegreerde oplossing. In het algemeen hielden zij er een 'generate and test' strategie op na.

'Intermediates' vertoonden in het algemeen een probleemgeoriënteerde aanpak. Hoewel logisch redeneren als strategie in het ontwerpen meestal als niet-relevant wordt afgedaan, werd toch door de meesten een vorm van redeneren, ook wel bekend als 'forward reasoning', toegepast. Zij probeerden tevens hun eigen kennis aan te vullen met een grote hoeveelheid externe informatie. Echter, voor de helft van hun lukte het niet om de informatie op te nemen en te integreren in een uitgewerkte probleem-representatie.
Ondanks de gevonden verschillen is het 'novice-expert' paradigma niet valide voor het verklaren en voorspellen van verschillen in ontwerpcreativiteit. De wijze waarop een kennisstructuur is opgebouwd door het ontwikkelen van een 'macrostructuur' teneinde het probleem op te lossen, lijkt doorslaggevend. Er zijn aanwijzingen te vinden voor deze nog voorlopige conclusie.
Op basis van de bevindingen wordt ten slotte aandacht besteed aan de implicaties voor het onderwijs.

Voor toekomstig onderzoek is het noodzakelijk de ontwikkeling van de kennisbasis van ontwerpers nader te bestuderen. Het oplossen van slecht gedefinieerde ontwerpproblemen vraagt om een eigen domeinspecifieke benadering die in sommige opzichten afwijkt van die in andere domeinen. Deze studie toonde aan dat, door de creativiteit van de oplossing te betrekken in de analyse van het voorafgaande proces, de data in een nieuw licht komen te staan.

Chapter 1 Introduction

1.1 *Background*

In this book a series of studies are described concerning the human activity of designing. More specifically, these studies are performed within the educational setting of the School of Industrial Design Engineering at Delft University of Technology in The Netherlands. As such they form part of the research programme in design methodology there. The objective of that research programme is to improve design methods for practical application, to develop design tools and to improve design education. Not all of these aims are pursued in the studies described here. In this book the design education system is used to obtain empirical data and to base the resultant recommendations on.
The main objective is to gain a deeper understanding of the nature of the design activity as performed by students. According to the view of Cross (1990), through better understanding, design educators may be better able to nurture the process.
This chapter describes the books background, gives a brief overview of the empirical studies conducted, and shows the linkage between these apparently differing studies.
The motive behind the studies described is that designing, and thus design education, still lacks any solid scientific foundation. Consequently, like Dixon (1989) states, with respect to engineering design, design education and practice are:

> "...too much guided by specialized empiricism, intuition, and experience." (Dixon, p. 317).

1.1.1 *The domain of industrial design*

For an understanding of what designing is and how design knowledge can be most effectively acquired, a domain definition must be obtained. In spite of numerous studies on designing, very few operational definitions of it are proposed. This is probably due to the existence of a myriad of 'subdomains' throughout the overall domain. It is obvious that designs from architectural designers differ in many respects of the designs of industrial designers or design engineers. For industrial design one of the definitions used by ICSID (1964) is:

> "Industrial design is a creative activity whose aim is to determine the formal qualities of objects produced by industry. These formal qualities include external features but are principally those structural and functional relationships which convert a system to a coherent unity both from the

point of view of the producer and the user. Industrial design extends to embrace all aspects of human environment which are conditioned by industrial production."

At least two aspects in this definition are of importance. The first one is the concept of creativity which is apparently an important criterion as to the quality of the design; and the second is related to the multidisciplinarity of industrial designing, ranging from the applied arts to engineering. However, it is far removed from an operational definition which could give clues regarding the knowledge involved.
Returning to a more general level of design similarities can be found between subdomains. In reviewing studies of design, Cross (1990) summarizes what designers do and what their abilities are. He distinghuishes, as the core features, the ability to:

- "resolve ill-defined problems
- adopt solution-focussing strategies
- employ abductive/productive/appositional thinking
- use non-verbal, graphic/spatial modelling media" (Cross, 1990, p. 132).

As a basic impression this distinction is very useful, but for each feature a further analysis is required. In other words, what knowledge and skills within the domain are necessary tools for a designer and how is design expertise acquired?

1.1.2 *Design education*

Cross (1990) observes that the increased attention towards design education in the last decade has exposed the lack of any clearly-articulated and well-understood principles. The problem is due partly to the fact that, educationally, design methods are often derived from prescriptive models, which claim to offer systematic methods concerning the execution of design. However, in general these models are not based on firmly validated theories. Moreover, they mostly offer rather general recommendations; for example a prescribed sequence of design phases is presented as a heuristic which should benefit the quality of the result; next, each of these phases is then qualitatively described in more or less detail. As Dixon (1989) states, these models are subjective prescriptions and not scientific theories. They cannot, and thus are not, validated. It is believed here that design research is in a 'pre-theory' stage where much of the research is devoted to generating models and hypotheses, rather than testing them. Seeking predictions is premature.
An extensive description of different models in design and design education is beyond the scope of this study. For an overview of the relevant literature, see Finger & Dixon (1989) and Tang (1989). However, in order to clarify the fact that design methods in education are often derived from prescriptive models, a short description will be presented here of design education at the School of Industrial Design Engineering, Delft University. This academic discipline is characterized by the need for integrating four relevant subdisciplines: engineering, aesthetics/styling, ergonomics and new product development (innovation management and marketing); see figure 1.1. Assignments within this domain tend to include

the product development process as a whole, from the first definition of the problem to detailing of products in technical drawings. More than in any other school of industrial design the engineering aspects are emphasized. Design education then is aiming at the synthesis of the relevant disciplines.[1]

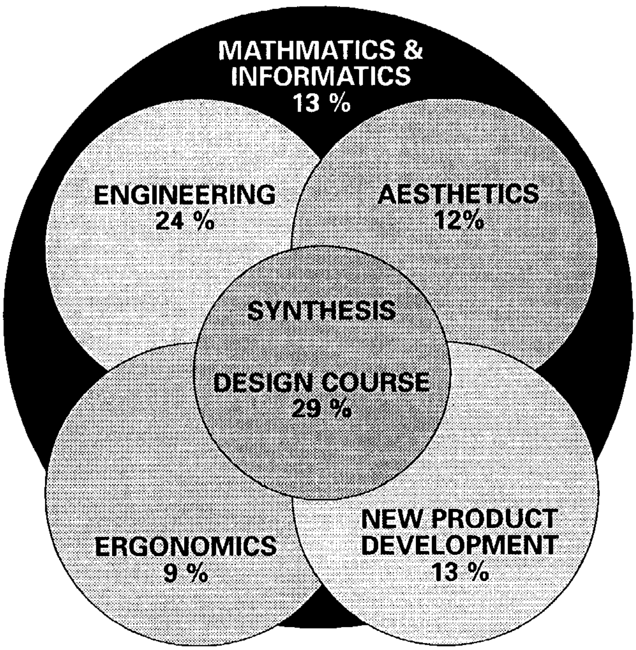

Figure 1.1 Domain-specific knowledge in design

The educational methods in design are mainly derived from the methodological work of Roozenburg & Eekels (1991). They offer models and methods according to the European tradition of subjective prescriptions, such as Pahl and Beitz (1984). One of their contributions is the assumption of a 'basic cycle' of design (figure 1.2), which they consider the most fundamental model of the design process.
The authors assume that all design processes are structured in this way:

> "That finding leads nearly imperatively to the statement: effective design processes should be structured this way. The structure-model, as is discovered descriptively (the cycle), is turning into a methodical standard for effective design." (Roozenburg & Eekels, p. 84; translated from Dutch)

[1] Throughout the book terms such as *industrial design* and *design* refer to this specific domain of industrial design engineering.

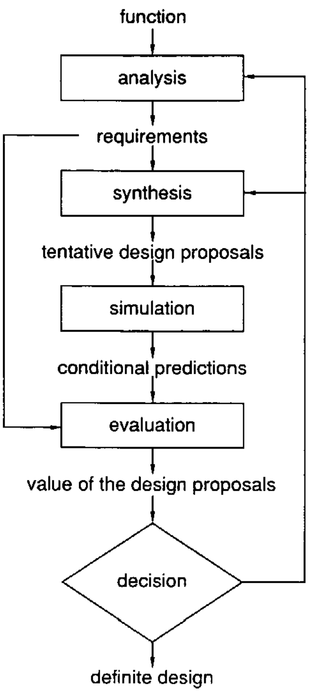

Figure 1.2 The basic cycle of design (Roozenburg and Eekels, 1991)

Although they apparently state that the structure is derived from experience, no evidence at all is offered nor is the effectiveness of the basic cycle validated. Perhaps evidence is unnecessary as this structure is *de facto* a very rough description of nearly every problem solving process, and as such applicable to every problem.

However, the design course studied is indeed structured in a rather rigid sequence according to the phases described in the basic cycle. The coursebook is also structured in this fashion, offering students a detailed description of each phase although without really transmitting design methods on the 'how' of designing. In each project students are taught to begin with analysing the problem by gathering relevant information. From this analysis a list of requirements is derived. Next, the idea generation phase is approached, etc. This sense of travelling through a fixed, ordered, design cycle is reinforced by the penultimate project task - the technical report.

In line with most design schools the educational process here relies on the project method. From the first to the final year students spend a proportion of their time involved in design projects, working in groups or individually. 'Learning-by-doing' is the device and is regarded as the only way to grasp the topic.

However, there is a problem in that the basic educational processes of how to design, how to take decisions or how to effectuate integration of information from relevant disciplines (engineering, designing, ergonomics, and business) are poorly understood. Instead, design education as a 'learning by doing' activity is often assumed to be a kind of self-reflective learning, which is more influenced by personal maturity of the students then by goal-directed instruction. Within this perspective the introduction of the 'learner report' as a teaching tool was a logical step (van Eyk, 1982). As part of the design task first-year students had to write their learning experiences immediately after each project (this topic is returned to in chapter 3). Again, by this tool the student's own responsibility for the learning process was stressed. In short it is suggested here that too little attention is paid to the core features of design. Indeed, it is questioned whether the following statement of Simon (1977), still holds for current design education:

> "...While analysis has become orderly, systematic, theory-based, synthesis (design) has remained artistic, implicit, intuitive - and, as a result, nearly unteachable. The curricula have simply responded to this imbalance in progress. In the universities, we teach what we can teach; and increasingly, what we can teach is analysis." (Simon, 1977)

Related to one of the studies described in chapter 4, six design teachers were asked to indicate what an industrial designer should have learnt from design education. They specified the following *expectations*:

"We expect that students will be able to:
(on the *process*)
- structure their own design process, using planning as an important tool to control what they do,
- discern between strategic decisions and those on the level of content,
- provide certain intermediate results such as a programme of requirements, principal solutions and concepts,
- adapt their way of working to the assignment and to the resources and time available,

(on *handling of information*)
- gather information in a systematic way, consider it critically, and discern between more and less important things,
- weigh information, and solve inconsistencies,
- discern between different kinds and levels of information and knowledge,

(on *reasoning*)
- reason subtly from function to form, (the methods suggest concentric development) in a controlled and goal-directed way,
- integrate different forms of reasoning involved in the different kinds of requirements,

(on *ideas/creativity*)
- have innovative, creative ideas, and use creativity techniques if necessary,
- look for possibilities of innovation,
- feel challenged by the assignment, and be highly motivated to design,
- display an innovative attitude,

(on *ways of working*)
- be visually oriented, sketch and draw a lot, and prepare or make models while working in 3D in order to visualize the situation more clearly,
- be independent and self-sufficient in the ways they work,

(on *designs*)
- make some resultant creative designs from the design brief,
- do very well in the conceptual phase, and possibly perform a little weaker in the embodiment phase (especially novices, through lack of detailed design knowledge),

(on *results*)
- come up with innovative designs, dependent on their level of expertise, and their design capabilities."

With this overview of possible characteristics of an industrial designer there is a starting-point to investigate the real nature of design education.

1.2 *A cognitive approach*

Over the past two decades more and more research within cognitive science has focused on the understanding of problem-solving expertise throughout different domains. In Ericsson and

Smith (1991) a number of these studies concerning areas such as chess, physics, medicine, athletics and music are described. A primary research aim is the understanding of the process of acquiring knowledge and skills that lead to outstanding performance.
Within the domain of designing attention to similar research topics can be noted, although the studies are not directly related to design education. In general, the assumpion is that the problem-solving process in design is qualitatively similar to processes that have been observed in solving routine problems within other domains. As Akin (1986) states:

> "Then, *although designers' knowledge and behaviors may vary, their basic information-handling capabilities such as encoding, manipulation, and recall of information, are essentially similar to the capabilities observed in other task contexts.*" (Akin, 1986, p.20; italics by Akin)

A similar conclusion was made by Langley et al. (1987) with regard to the area of scientific discovery, but again pertaining to rather general strategic aspects of problem solving.
However, if focus is held again on the similarity between the general principles of problem-solving behaviour, then headway on the existing description of phases within the process will not be made. Analysis of the specific domain knowledge of industrial design must be achieved first.
The conclusion being, that if an understanding of design and design education is demanded, then new theories on the subject must be generated. At this stage it is assumed the best way to start is to gather data, and to identify relevant variables. For that purpose a cognitive approach is adopted, intending to reveal information that is processed and selected, and the knowledge that is activated. Understanding the design process is understanding the mental behaviour of the designer in relation to its context variables. Right from the start of this project, in 1986, a view shared with Dixon (1989), that *knowledge* is one of the crucial factors in order to understand design, was adopted. Relevant questions include: What is the effect of prior knowledge and expertise in design; and in talking about its effect what relationship exists between the knowledge base of the designer and the quality of the result? In the same way the question of acquiring knowledge in design education is crucial. Hence, in order to teach design an investigation of what knowledge is critical must be performed firstly.

As a guide to the rest of the book, the research aims are now presented together with a short introduction to chapters 2 to 5.

1.3 *Research aims*

The general aim of the empirical studies conducted in this book is, to give design and design education a scientific base which can contribute to the development of design methods and educational principles. Because design theories are nonexistent, the focus is placed on the exploration of the domain and trying to answer the following research questions: (1) What is design expertise? (2) What is the role of domain knowledge in design, and what is the

influence on performance quality? (3) What characterises the expertise of novice designers compared to that of a designers at an intermediate level? (4) Is there any relationship between expertise and performance quality?
By domain knowledge is meant all knowledge and skills of the industrial designer with respect to content and strategies. In chapter 3 the knowledge concept is further explained.
The questions mentioned above lead to two other aims of the study. Firstly, in order to define and measure 'performance quality' the study begins with an analysis of the creativity concept from which a definition is derived. In this study, hypotheses are tested with regard to the measurement of creativity. Secondly, because of methodological problems, the methods used in exploring information processing in various domains are still debatable. In this study different methods will be used and compared.
A further explanation of what is included in the next chapters must be illustrated.

1.3.1 *Issues excluded from exploration*

The research aim above could lead to a vast range of study issues. However, not all of these issues are pursued in the studies described here. The scope is limited in several ways. Firstly, as mentioned previously it is intended to include only product design.
Although the term 'designing' pertains not only to the design of artifacts (the designing of more abstract systems is also involved) within this study empirical data concerning the design process are mainly derived from the design of products. Nevertheless, because our focus is on the process, it's expected that the conclusions based on these studies will have broader application. The result of the process, a designed products quality, can be conceived of as a criterion which determines the success of the process followed.
Secondly, the theoretical approach chosen in this research project is a cognitive description of the design activity, i.e. the design process can be conceived as an information processing activity. In order to understand the design operation first a representation of how people perform this activity is needed. The mental task of designing involves processing and retrieving information and knowledge. Describing the effect of the designers' knowledge on the design process and the design can help understand this mental activity. Hence investigations into other relevant variables which characterize the person or the situation will not be dealt with.
Thirdly, in this book the area of concern is design education. Research is conducted in a school of Industrial Design Engineering. Within an educational setting, as compared to professional design practice, it is easier to control the variables studied or to variate the desired ones. As long as studies in the domain of industrial design engineering are lacking, the choice of an education environment, with designers on novice and intermediate levels of expertise, seems a good starting point.
Finally, the study is focused on the individuals design activity, although it's realized the design activity involves mostly team-work. On face value observing design teams has therefore benefits, although it also brings with it considerable methodological problems. Moreover, in this study the behaviour of the individual designer is of primary interest.

1.3.2 *Issues incorporated*

In relation to the aim of the study, mentioned previously, important research questions are, what methodology underlies the design activity; what knowledge related to the end result is important in solving design problems; how can the knowledge base of the designer be analyzed; what is the influence of the education programme on designing? To answer these questions various studies are performed using different research methods. Firstly, in order to evaluate the design process in terms of what knowledge is important, the role of knowledge on the quality of the design or artifact is measured. Therefore, a criterion is needed to gauge the standard of design in an educational setting. Although it seems obvious to use the grades given by design teachers, a number of studies performed into the reliability of these evaluations show that the official marks are not reliable enough for this purpose (Christiaans, 1990). In order to define another criterion it is necessary to know what is the purpose of design. As mentioned before, designing is a creative activity, as it aims to generate original ideas. New designs are expected to bring improved qualities to the already designed world. Thus, as far as *creativity* is a salient criterion of design, this will be used as the criterion if reliable measurement is possible.
Secondly, to understand the role of knowledge in design the design process must be observed and the knowledge designers use elicited. Because of the explorative nature of our studies, it is fruitful to use different elicitation methods. By this it is possible to compare the effectiveness of the methods used. Moreover, methodological issues are concerned with how knowledge elicited from designers can be encoded. These issues are stressed in the studies.

1.4 *Contents of this book*

The studies described over chapters 2 to 5 are divided in three parts. They form part of the research programme at Delft University, faculty of Industrial Design Engineering.
In part one, chapter 2, an exploration will be presented concerning the measurability of creativity within the domain of industrial designing. The objective is to find a reliable and valid criterion in order to measure the effect of what is going on during the design process. It was decided the only feasible way of measuring creativity is to adopt a 'product definition' of the concept. It is shown that with the help of a 'consensual assessment technique' based on this definition, creativity can be measured reliably. The product creativity rating is used in the subsequent studies on design process. Studies in this first part were conducted between 1986 and 1989.

The role of knowledge in design is the subject of parts two and three. Studies are presented concerned with the knowledge base of the designer. The first question to explore here is, what knowledge is used during the design process, and second, what knowledge is really important as regards the creativity of the design.
Different elicitation techniques are employed. In part two, chapter 3, the 'learner reports' of first-year students will be analyzed according to a knowledge-categorization model, and the

methodology of how to analyse and measure knowledge, in terms of a classification of knowledge types, will be illustrated. The problems of analysing *retrospective* data is raised and discussed. Data were used from students who were involved in the first-year design courses of 1985/1986 and 1988/1989.
In chapter 4 a study is described in which a direct way of knowledge elicitation is chosen. Design students with different levels of expertise are observed whilst performing a design task. The thinking-aloud protocols of these 'novice' and 'intermediate' designers are then analyzed. This study was conducted between the months of September and December 1990.
In chapter 5 the overall conclusions are described, and results of the studies related to design education. Recommendations with regard to education and to further research are made.

Chapter 2 *Creativity as a design criterion*

2.1 *Introduction*

The aim of the studies described in this chapter is to provide a criterion measure to determine, by analysing the product designed, the effect of what goes on within the design process on the resultant artifact. In descriptions about the qualities of a designer the concept of *creativity* is a dominant factor. The result of a design activity must be something novel and original, adding a surplus value to the already designed world. It is not surprising that creativity is the ultimate goal of most design schools. The demand for creativity seems a very reasonable one, but in practice it is unclear what people understand by it. Nowadays the concept is fashionable and in common usage. Expressions like "creative cooking" or "creative bookkeeping" confuse the portrayal and hamper the use of the concept for scientific purposes. Dresden (1987) poses that writing on creativity bears witness to recklessness that inevitably will result in failure. Overall there is a very vague idea about the concept; although it commands continual attention, especially in relation to product innovation, it cannot be explained merely by 'wishful thinking'. If nothing else this reveals that the creativity concept has a certain face validity. Moreover, the common use of the concept points to the presupposition that creativity can be stimulated by acquiring certain skills or by applying certain techniques. Finally, the attention suggests a positive estimation of creativity. However, if the aim is to analyse the creativity of designers in relation to design and design activities we have to get rid of confusing connotations.

In an educational setting it seems obvious to use the grades given by design teachers as a reliable criterion for design performance quality and creativity. However, a number of studies conducted into the reliability of these evaluations show that the official marks are not reliable enough for the purposes of this study (Christiaans, 1990). Agreement between teachers is low, correlations standing between .17 and .54. In practice a mark is determined by one teacher only. Moreover, the same teacher accompanies the student during the process. As a consequence the result will be influenced by the contribution of the teacher. Therefore, another criterion which can be measured reliably and validly must be found.

In this chapter an attempt will be made at defining creativity in such a way that it can help to evaluate the design process.

2.2 *Theory*

The act of designing is pre-eminently focused on generating creative solutions for ill-defined or ill-structured problems. However this statement does not provide any indications as to the meaning of creativity. If the concept of creativity is to be used in relation to the design and to design education, it must be defined in terms of measurable operations.
Despite the enormous amount of research on creativity in the last forty years it is very difficult to select an operational definition which is relevant for design and, more importantly, to find methods of assessment. Such a definition should indicate what operations of observation, registration, and of calculations have to be performed in order to estimate the quantitative or qualitative value of the relevant variable (De Groot, 1967). In literature, definitions are generated in terms of personality traits, the process itself, and the product. Within the *trait approach* it was attempted to ascertain the existence and organisation of stable human qualities (traits). One of the most important contributors to this approach was J.P. Guilford, who stated:

> "I have often defined an individual's personality as his unique pattern of traits. A trait is any relatively enduring way in which persons differ from one another. The psychologist is particularly interested in those traits that manifest themselves in performance; in other words, behaviour traits ... Creative personality is then a matter of those patterns of traits that are characteristic of creative persons." (Guilford, 1950, p. 444)

In support of this view extensive testing programmes were developed, among which were tests for measuring creativity. Because of the success of evaluating other traits, such as intelligence, endeavors to measure creativity were expected to give equally positive results. The creativity tests developed according to Guilford's 'structure-of-intellect' model are good examples of this approach. For educational purposes a focus on the trait approach, like that of Guilford (1950), is not particularly interesting, since a trait by definition is a very stable disposition and therefore not easy to influence by training. Feldman (1980) states:

> "Although a number of these intervention programs have enhanced performance on various creativity tests, the programs can be shown to have been misguided in the belief that raising test scores improves creative ability itself, misguided by the very logic of the trait definition of creativity. Since a trait approach to creativity assumes that the traits to be measured will express themselves under most existing environmental conditions, it follows by definition that these traits should not be easily influenced by training. If they are easily influenced, they probably are not traits; if they are not influenced, they are traits because training does not affect them significantly." (Feldman, 1980, p. 93)

The tests, which generally measure divergent and associative thinking, are also criticized by Ausubel et al. (1978) with regard to the validity problem. According to these authors the tests are essentially measuring supporting abilities and not creativity itself.
Hence, creativity tests that are analogous to most intelligence tests aimed at measuring a person's trait or 'talent', will not be considered here.

Unlike the trait approach the *process approach* is directed toward the interaction between the organism and the environment. Human behaviour is a function of both, i.e. the circumstances influence the way in which a human being shows his/her capacities. Wallach (1971), who criticizes the aforementioned creativity development programs, states:

> "If we want to learn about the enhancement of creativity, we had better consider training arrangements that make a person more competent at creative attainments themselves - such as writing novels well, excellence in acting, skill as a musician, or quality of art work produced." (Wallach, 1971, p. 23)

Within this approach theorists are not so much engaged in predicting who will excel in creativity as in investigating under what circumstances the individual will be creative. Creativity refers to mental processes that lead to solutions, ideas, theories, etc. Therefore much effort is put into describing in more or less detail, the stages of the creative process including its methods and techniques. It appears as if the process view by some is chosen in order to assume the relativity of the creativity concept; i.e. in their opinion, creativity should be estimated as novel for the creator.

Over the last two decades the process approach has been gaining attention as a consequence of the emphasis on cognitive theories. Several authors stress the general correspondence between the structure of a creative process and the structure of a problem-solving process (Newell & Simon, 1972; Simon, 1966; Greeno, 1980; Weisberg, 1988). For example Simon (1966 and 1967) developed a theory for creative thinking by way of a machine program. The stages of the creative process - preparation, incubation, illumination, and verification (Wallas, 1926) - are explained here in terms of 'familiarization' - a slow process for building up in long term memory a representation of the problem and of relevant data -, and 'selective forgetting' - only the representations stored in long-term memory will remain.

In chapter 3 the subject is raised again.

One of the more recent descriptions of the process was provided by Amabile (1983). She developed a 'componential framework' for creativity, as is depicted in figure 2.1.

In this model three main components are hypothesized, in each of which essential elements are found for producing creative responses. However, the enumeration within each frame is unlimited. The first component, domain-relevant skills, is concerned by Amabile to underlie every achievement. Important for creative behaviour seems to be the nature of the information within the relevant domain and the way in which it is stored in memory. Knowledge built up around general principles is, according to Amabile, of greater use than a specific collection of limited applicable facts. Creativity-relevant skills, the second component, are active only on the most general level and as such are not domain-specific. The third component is task motivation. As far as the motivation component is concerned Amabile points to the analogy between creative achievement and 'latent learning' in that it takes place mainly when task-irrelevant motivation is low.

1 DOMAIN-RELEVANT SKILLS	2 CREATIVITY-RELEVANT SKILLS	3 TASK MOTIVATION
includes: - Knowledge about the domain - Technical skills required - Special domain-relevant "talent" Depends on: - Innate cognitive abilities - Innate perceptual and motor skills - Formal and informal education	includes: - Appropriate cognitive style - Implicit or explicit knowledge of heuristics for generating novel ideas - Conducive work style Depends on: - Training - Experience in idea generation - Personality characteristics	Includes: - Attitude toward the task - Perceptions of own motivation for undertaking the task Depends on: - Initial level of intrinsic motivation toward the task - Presence or absence of salient extrinsic constraints in the social environment - Individual ability to cognitively minimize extrinsic constraints

Figure 2.1 Components of creative performance (From Amabile, 1983, p. 78)

In figure 2.2 Amabile's hypothesized creativity process is shown.
The successive stages are not new, but the assumed operation of the three components is of interest. In terms of information processing 'task motivation' is responsible for initiating and continuing the process. 'Domain-relevant skills' provide the materials which can be used during problem solving, while 'creativity-relevant skills' act as executive controllers. The hypothesis being that each component is conceived of as a necessary condition for creativity, but no single condition in itself is sufficient for eliciting creativity. The relevant issue in this approach is that the act of creativity is not understood as a result of a unique, extraordinary thought process, but evolves as a sequence of steps leading to a new state of knowledge based on what came before (Greeno, 1980; Langley et al, 1987; Weisberg, 1986). As Weisberg (1988) states:

> "This might mean, perhaps paradoxically, that in order to produce something new, one should first become as knowledgeable as possible about the old." (Weisberg, 1988, p. 173)

The process approach gives a valuable starting-point for analysing the factors influencing the problem-solving process. Moreover, the approach can contribute to the development of methods and techniques for education and practice. However like the trait approach it also fails to offer a clear criterion for creativity. Even the contribution of Amabile seems to serve no other purpose than to stress the supporting factors instead of creativity itself.

Within the context of design and design education it seems obvious that creativity should be recognized through the *product* or artifact. Many definitions of creativity indeed take a product view, considering it as the only tangible proof of someone's creativity. But by such view a myriad of definitions is hidden.

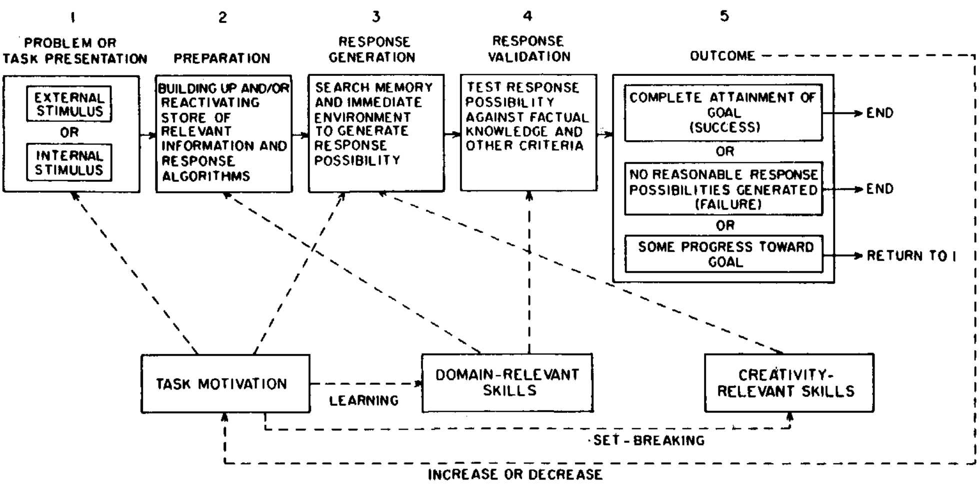

Figure 2.2 Componential framework of creativity (From Amabile, 1983, p. 78)

For some theorists a product is creative when it is unique to mankind, while for others the level of creativity is only related to the creator. In most definitions of creativity the following aspects, taken from Jackson & Messick (1965), are mentioned: *unusualness, appropriateness, transformational power,* and *condensation of meaning*. But again, these are hardly operationally defined concepts. Efforts undertaken to develop objective assessment techniques (e.g. Simonton, 1980) also failed to succeed because of difficulties in capturing the products or responses into quantifiable elements. De Groot (1963) on the other hand approached the issue in a different way when he posed the question of whether 'the creative' can be machine-programmed. In his definition he proposed three conditions:
1) Creating means the intentional making of something, a product. 2) The product must be novel in its present shape, in that it is neither a mere redesign nor a simple variation derived from existing things. 3) The product must be valuable according to some cultural appraisal. In his opinion each of these criteria is equivocal. The first one renders creativity much too dependent on the existence of technical resources. The novelty criterion, the second condition, raises another question: new for the creator or new for the culture? The 'cultural value' criterion also has little to aid its interpretation. All the more reason, as De Groot says, to state that the creativity concept is in fact useless. It is doubtful whether this rigorous statement is the only solution for the criterion problem. Unless the concept of creativity lends itself to meaningful distinctions and to the formulation of hypotheses, less rigid requirements for the definition should be allowed.

2.3 *Creativity and design*

In the relevant literature the relationship between creativity and design is often made, but the statements on the topic are in general very superficial. It is always stated that design is a

creative occupation and that designers are creative people (see e.g. Lawson, 1980). No domain-specific aspects of creativity are ever mentioned. Again most authors dwell on the design process, taking the view that the 'illumination' stage is really a sudden perception of a bright idea (Lawson, 1980; Cross, 1989). The main interest is in creativity methods like brainstorming and 'synectics', most of these methods claim to work by removing the mental blocks that inhibit creativity. In view of the fact that in industry these methods are very popular, people apparently expect miracles of them. But, although these methods indeed encourage people to generate ideas, it is difficult to prove whether they are really effective in bringing about exceptionally creative novelties or discoveries. Firstly, if removing mental blocks actually stimulates creativity it is only one of the factors, as can be seen in the framework of Amabile (fig. 1). There ought to be a minimum level of basic knowledge within the domain in order to generate valuable ideas. Secondly, because they do not lend themselves to controlled experimental studies, research into the effects of creativity techniques is sparse. Thirdly, as Dresden (1987) says, discussing the problem with colleagues or friends is an older version of the same method, and would perhaps be more effective.

2.4 *Conclusion*

Within the area of research on creativity many theorists seem to be focused on a universal definition of the concept, taking as a starting point either the trait or process approach. The results are disappointing in that they do not provide information about what skills or specific situations are creativity-relevant. On the other hand, if domain-specific elements are also influence creativity, as is assumed in Amabile's framework (fig. 1) and by other theorists, research on the topic can better be aimed specifically at investigating factors within each domain that influence creativity.

An example may illustrate this assumption. In the domain of the fine arts the concept of creativity has a different meaning than in the domain of engineering. Dresden (1987) illustrates the difference on the basis of the concepts 'art' and 'craft'. In the artistic act of creating both elements are proportionally present and distinguishable, although they are also indissolubly related. Through the centuries the proportion of art and craft has varied. In the middle ages the artist was above all a craftsman. So, in art education one started with learning to copy faithfully the successful examples of former artists. During subsequent centuries this form of plagiarism or mimicking indeed disappeared, although even in the nineteenth and twentieth centuries other artists work was used as a source of inspiration. There is a striking resemblance for example between the famous painting "De aardappeleters" (potato eaters) from 1885 of Vincent van Gogh and Emil Otto Grundmann's "Prière avant le repas" from 1876 (NRC, 1990; see figure 2.3). In the book 'creative copies (Haverkamp-Begemann, 1988) examples of interpretative drawings are collected.

Considering the end products of fine art in the present day situation, the 'art' - the artistry, the expression of the novel idea - must cancel the 'craft'. Within engineering on the other hand the craft will dominate and be evaluated as such on, for example, the level of perfection and appropriateness. As a consequence creativity in engineering can probably be defined and

studied as a special mode of problem-solving. However, as far as artistic creativity is concerned that paradigm may perhaps be unsuitable.

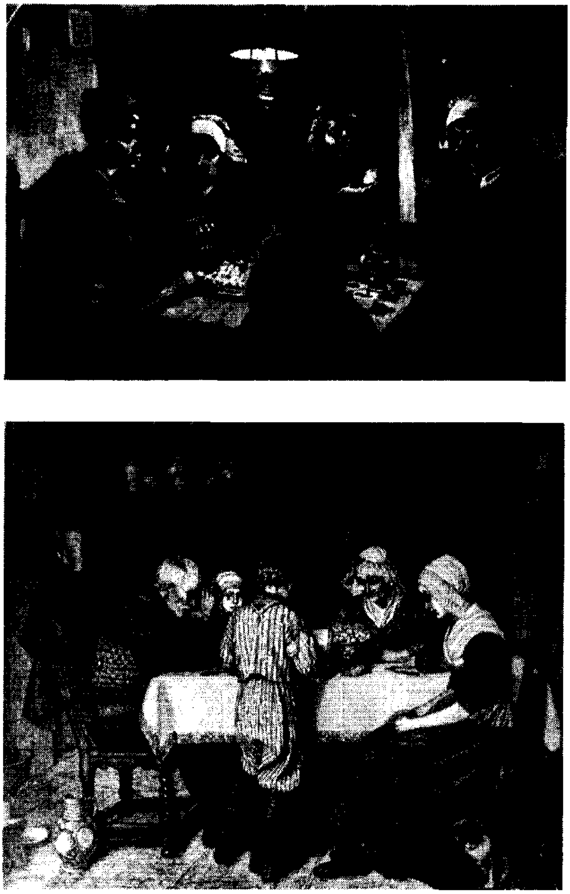

Figure 2.3 Example of mimicking in art

In short, it may be better to forestall employing a universal definition of creativity. This book is dedicated to industrial design engineering, so with regard to creativity it is based on the following assumptions:

- The concept of creativity is only meaningful within the context of the domain at issue. Research ought to be directed at the differences between domains. Relevant questions in this respect are: What aspects determine, within a domain, the creativity and can one's creativity be increased by training?

- In the search for a measure of creativity within the domain of industrial design engineering the product approach seems the most practicable route to follow. One argument for this choice is of course the 'measurableness' of products. Another argument is derived from the view that the product reflects the process which preceded it (Weisberg, 1988). In the next section this choice will be further explained.
- We adopt the view that creativity can only be conceived of as a 'relative' concept. Firstly, the judgement of what is creative or not is culturally defined, i.e. influenced by time, by domain and by ideas of people or groups. Secondly, especially when applied to education, the view that within a domain there are different levels of creativity has to be adopted. Within the domain of design engineering, design develops in and by a network of already existing designs, creating a totally new object is impossible. The result of a creative process is expected to be new to the extent that it is not a mere reproduction of the existing object or system. This assumption can only be confirmed by showing that even the products of novel designers can be assessed reliably.

In the next section the assessment of creativity by making use of design artifacts will be discussed.

2.5 *Creativity assessment*

In assessing creativity within the domain of design engineering attention is aimed toward developing a technique that can measure the concept in a reliable and efficient way. It is only then that creativity can be used as a criterion in this research. However, until now creativity researchers have been relatively unsuccessful in measuring creativity by objective methods. The reasons for this failure are very well described by Hofstee (1985b). One of the reasons, he says, is that the need for objectivity by formalizing the measurement leads to a reduction of the product features to be appraised. Features that are difficult to determine will, on the whole, be neglected. Another possible reason is, that the core of the creativity concept does not lend itself to formalization into an objective instrument, because it is made up of aspects like originality, novelty and unexpectedness. Concepts like creativity and quality have, according to Hofstee, an 'emergent' character, i.e. they are defined again and again on the basis of new creations so there is no possibility for previous programming. Only the human judge can *ad hoc* estimate the originality of a product; and the fallibility of the judge gives no reason whatsoever to kick him/her out of the system (Hofstee, 1985b). Therefore, in estimating the creativity of products we have to lean on human judgement.

In different settings this is daily practice. In, for example, design or art education, teachers evaluate the results of their students. And what about the phenomenon of judging which design or book will be considered for a prize? Even in determining the quality of fish - freshness, smell, taste - TNO's Instituut voor Visserijprodukten (Institute for Fishery Products) makes use of judges in 'taste panels'. As reported, results are good, especially using trained adjudicators (NRC, 1990). Another example is the assessment of the quality of grant applications concerning scientific research. As reported by Hofstee (1983), who studied

this assessment practice in The Netherlands, the average correlation between the five judges, based on the final judgements, was only .14. The estimated reliability (Spearman-Brown), was .45. When looking at the separate judgement attributes the intercorrelations were between .12 and .29. A supplementary study of Scheerens & Beem (1986) confirmed these results. This example demonstrates that even if large sums of money are invested and judges are doing a rather poor job, people's confidence in human judgement remains.

In creativity assessment, especially for research purposes, human judges are also used. This research tradition began with the famous study of MacKinnon (1962) among architects. In all subsequent studies the question has been how to overcome subjectivity within these assessments. In the work of Amabile (1982) a possible answer is provided. She developed an assessment technique in which she adopts an operational definition that relies on clearly subjective criteria:

> "A product or response is creative to the extent that appropriate observers independently agree it is creative. Appropriate observers are those familiar with the domain in which the product was created or the response articulated. Thus, creativity can be regarded as the quality of products or responses judged to be creative by appropriate observers, and it can also be regarded as the process by which something so judged is produced." (Amabile, 1982, p. 1001)

The meaning of the adjective 'appropriate' depends, as she says, on the level of complexity of the domain. For some domains a moderate level of exposure to the domain is sufficient. Other domains are so complex that an expert level is required to judge the creativity of the products.

The measure of 'inter-subjective' agreement (De Groot, 1961) provides a good indication of the degree of stability in this kind of judging and the possibility of subsequent realization of the creativity concept as an appropriate instrument. Research conducted in this field may shed some light on the reliability and the validity of this measurement technique. A brief overview of literature concerned with 'product creativity rating' is presented here.

2.5.1 *Reliability*

A study by Wallen & Stevenson (1960) was concerned with creativity in writing by fifth grade school children. Four sets of compositions, made during the year, from 63 students were rated independently by teachers according to a previously articulated definition of creativity. The intercorrelations of judges by pairs initially ranged from .57 to .68. After a discussion of the points of disagreement the same compositions were judged again with resulting interjudge correlations between .70 and .80. By taking the average rating for each student the consistency between the sets of compositions was measured, resulting in correlations between the sets from .81 to .86. No information is provided on the correlation coefficient used. The authors mention rather high correlations with certain achievement measures and with an intelligence test, ranging from .57 to .72. Eisner (1965) asked 85 sixth-grade pupils to produce two kinds of art work. One required nine drawings within a booklet,

in which on every page beforehand had been drawn a simple line, while th second task was to produce a piece of sculpture. For both tasks there was a time limit. Three judges with expertise in the domain had to judge independently the creativity of these works on four aspects:

- 'Boundary pushing': "..the process of extending the limits of common objects" (p. 127).
- 'Inventing': "..the process of employing the known to create an essentially new object or class of objects" (p. 127).
- 'Boundary breaking': "..the rejection or reversal of accepted assumptions" (p. 128).
- 'Aesthetic organizing': "..the presence in objects of a high degree of coherence and harmony" (p. 129).

During a period of two weeks the judges were trained by discussing the criteria and by practice in judging similar works. The product-moment correlations for overall interjudge agreement were .72, .78 and .82. Taking the two media separately, the coefficients for the sculptures were .61, .65 and .74, and for the drawings .71, .79 and .80. Finally, when the type and locus in each medium was taken individually, the coefficients ranged from .10 to .90. The correlation between the two media for each pupil was only .11. Eisner et al. found low intercorrelations between the four aspects of creativity, and between these measures and IQ (Binet).
In a study of Trowbridge & Charles (1966) paintings produced by 75 children from 3 to 18 years of age, who were attending classes at a municipal art centre, were judged by three "competent critics of children's art" (p. 282). Two paintings produced by each child were selected at random. The paintings were judged on creativity and technical competence. Although judges were given no information about the content of both criteria, they did discuss it informally. The agreement between the judges was high, as was substantiated by the low variance component of .05, and by the three interjudge reliability coefficients of .81, .80 and .76 (kind of coefficient unknown). The correlation between the two paintings for each student was .72. Finally, the hypothesis that creativity and technical competence can be considered as two separate factors was supported. The correlation between creativity scores and competence scores was .62.
Ward & Cox (1974) studied creativity outside the school. They used the products produced by people who competed in a radio station contest. Listeners were invited to submit "humorous and original little green things" (p. 202). In two studies 314 products were judged. In the first study judges, 4 research assistants without expertise in art or design, were asked to rate each object on 'originality', using a seven-point scale. The intercorrelations between the judges ranged from .41 to .61. The reliability of the average score was .80 (the authors refer to Winer, 1971). In the second study a distinction was made between 'found things' ("objects (-) in their preexisting state, natural or manufactured, without significant addition or alteration by the contributor"; p. 206) and 'made things' ("..those to which some change was made"; p.207). The intercorrelations between the 10 judges of the 'found things' ranged from .02 to .63, and between the 8 judges of the 'made things' from .18 to .63. It seems the rather low correlations between judges were due to a lack of expertise.

In a study by Getzels & Csikszentmihalyi (1976) products of fine art students were judged on three attributes: overall aesthetic value, originality and craftsmanship. The product was a drawing, representing a still life of objects that were shown in the experimental setting. Four groups of 5 judges were involved: artists (experienced in judging), art teachers, mathematics students and business students. With regard to the originality criterion the interjudge agreement, i.e. the average intercorrelation, between the artists was .31, between the art teachers .47, between the maths students .45 and between the business students .35. The reliability coefficients with regard to the overall aesthetic value and craftsmanship were comparable, the agreement between the four groups of judges ranged from .56 to .83. Within each of the groups of judges high intercorrelations were found between the three assessment attributes. These intercorrelations were highest in the group of experts because, according to the authors, experts were unable to analyse works of art in terms of separate criteria; that is, a product which was rated high on originality also got similarly high rates on aesthetic value and craftmanship.
In 13 studies Amabile (1983) tested her 'consensual assessment technique'. This technique differs in some respects from earlier methods used. In addition to the need for domain familiarity and for independence in assessing the products, judges were asked to rate the products on each attribute relative to one another. Ordering the products and attributes randomly was a final requirement of the assessment procedure. In judging products on visual and verbal creativity high interjudge reliability was measured (based on the Spearman-Brown calculation), ranging from .72 to .93, while the groups of judges ranged from 6 to 21. In more than half of these studies the rank correlation between creativity and technical quality exceeded .65. In her experiments judging verbal creativity (poetry) this correlation even reached .94.

2.5.2 *Construct validity*

If the agreement between judges can be understood as a measure of the reliability or reproducibility of the measuring instrument, the aforementioned studies yield promising results, especially when 'appropriate' judges are involved. But another question concerns whether creativity, as determined by the rates of human judges, has any construct validity. The assumption of Amabile, that the high reliability measures in all her studies are also proof of validity, is doubtful. Amabile (1982):

> "(-) the method provides measures of a construct that behaves as creativity was predicted to behave on the basis of theoretical derivations." (Amabile, 1982, p. 1010)

Another way to look at this question is to analyse the association between measures of creativity and of adjacent constructs. In the aforementioned studies correlations with a small number of other constructs are reported. Two variables seem obvious in assessing art and design products. One of these is the aesthetic value of the product, which in some studies is strongly related to originality and creativity (Getzels & Csikszentmihalyi, 1976; Amabile, 1983). Although in Eisner's study the aspect of 'aesthetic organizing' is hardly related to his

creativity measures. The second variable is 'technical quality' or craftsmanship. Here the findings are even more contradictory. In the study of Trowbridge and Charles (1966) the hypothesis that creativity and technical competence can be separated into two distinct variables is confirmed with a correlation of nearly zero. To the contrary the relationship between the two is rather strong in the studies of Getzels & Csikszentmihalyi (1976) and in most of Amabile's studies (1983). Nevertheless Amabile (1982, 1983) concludes that creativity can be considered a separate 'subjective' construct; there was, psychologically, a difference felt between the assessment of creativity as compared to that of technical competence and aesthetic appeal.

In short, with respect to reliability most studies point to the conclusion, that interjudge reliability is high. On the other hand the findings regarding the question of validity do not appear very concrete. Although judges apparently distinguish easily between various assessment attributes, the results of correlational analysis do not confirm any clear distinction between them. Hence, the question still remains whether creativity can be identified as a separate construct. In order to contribute to this validity discussion a more substantive analysis of the subject is needed, first by attempting to find an explanation for the high inter-rater agreement in the aforementioned studies, and next by testing some hypotheses with regard to the validity question.

2.5.3 *Matching against prototype*

As far as creativity is concerned, the agreement between judges in assessing it asks for a further understanding of the way people evaluate objects in their environment. Because research on this specific topic does not exist, dependence on studies in related fields is necessary. One juxtaposed concept is 'aesthetic preference', an assessment attribute that is often studied in relation to works of art. The most obvious explanation for the high degree of agreement between judges is the existence of a common cultural background. A study by Child (1970) into cultural difference in relation to aesthetic preference for works of art is relevant here. It shows that the agreement within and between different cultural groups was reasonably high, but highest for groups with an interest in art or with a higher education level. According to Temme (1983) this finding may suggest that groups with more common learning experiences in the field of aesthetic preference show a higher level of agreement with the judgements of experts. The same author pays particular attention to the proportional influence of the physical and social surroundings of the subject. As the stimuli become less tangible and people feel uncertain, the social stimuli become more important; this might be a consequence of the need for uncertainty reduction. It is also known that within groups certain forces are active which lead to their opinions becoming uniform, e.g. peer group pressure.

The idea of the common cultural background can perhaps also be translated in terms of the information-processing theory. The way people judge objects is only one particular case of the perception process. Theories on how information is encoded, stored and represented in memory stress the existence of mental structures. What is seen depends not only on the object

you look at, but also on how the visual system organizes and interprets the images which fall on the retina. Perceptual experience seems to be the result of a categorization process. In order to select, store and retrieve information from the vast amount of stimuli, people tend to categorize it within meaningful structures. Within these structures, with different levels of abstraction, chunks of information are stored. Most theories assume people, on for example an object, store features and relationships between features so that incoming information is 'matched' with the previous representation of it; also called 'default values'. It is suggested, that this representation serves as the 'prototype' for that category of objects; i.e. the human mind abstracts a form of a 'summary' from a variety of visual cues from a category of objects which correspond to the 'average' of those objects (Rosch & Mervis, 1975; Posner & Shulman, 1979). The basic idea is that before new information is processed it is estimated according to similarity or dissimilarity with prototypical examples, i.e. mental representations of concrete objects. Aesthetic responses, however, cannot be fully understood through simply this basic idea of information processing. Research on aesthetics shows that the emotional impact of stimuli has to be considered as well. Berlyne (1971) introduced the concept of "arousal potential" which relates to the activation of the nervous system. Various properties of the stimulus like novelty, unexpectedness, complexity and ambiguity will determine the level of arousal. According to Purcell (1984) the theory of emotion of Mandler (1975) can be applied. Due to a blocking effect when confronted with unexpected (non default) values of a stimulus, further attention, activity and emotional experience are aroused within the observer. The intensity and type of the response will govern the characteristics of the emotion experienced; for example varying:

> "...from pleasant attractive feelings (at low levels of blocking and type of unexpectedness combined with successful processing of the discrepancy through excitement and extreme interest) to extremely negative emotions (resulting from extreme and unusual alterations to an expected pattern in association with failure to resolve the discrepancy by extra cognitive processing." (Purcell, 1984, p. 192)

If the theory of category formation in storing information holds, then it follows, according to Purcell, that the attractiveness of the stimulus increases to the extent that it is closer to the prototypical representation of that stimulus. This hypothesis has been tested through studies on judging houses (1984) and landscapes (1985) which show indeed a close relationship between attractiveness and the prototypical 'value' of the objects, closer than the relationship between prototypical value and two adjacent attributes, 'interest' and 'preference'.

What then can these theoretical notions contribute to the validity question with regard to creativity? In general, inter-relationships between attributes can shed light on the identity of each of these attributes. In view of the aim of our study it is relevant to determine the distance between the creativity attribute and related attributes such as aesthetic appeal, technical quality, and so on. Some of the aforementioned studies show that creativity obviously has an aesthetical component, which recurs in the form of various definitions (Jackson & Messick, 1965; Eisner, 1965). In for example Amabile's studies, although she

argues there is a psychological difference between the components, the correlation is nevertheless quite high. If we assume that in assessing the aesthetic appeal of an object the judge will first compare this object to his minds prototypical representation of it, the distance between the observed object and the prototypical representation can be used as a discriminating factor between the creativity attribute and the aesthetical attribute. In other words, according to the previous theory, the attractiveness of an object increases by getting closer to its prototypical representation. Objects which by their originality, novelty and unexpectedness are by definition far from any prototypical representation, will thus have lower attractiveness because of their great distance from the prototype. Since creativity is also characterized by concepts like originality and novelty, the distance between a creative object and the prototypical representation, based on membership of the category of similar objects, is also by definition large, larger than the distance between the aesthetic appeal and prototypical value.

2.6 *Hypotheses*

In the next studies on creativity the following hypotheses will be tested.

Hypothesis 1:

Observers who are familiar with the domain of industrial design engineering will agree independently which designs are creative and which are not. The level of agreement will be an indication for the reliability with which creativity can be measured by the 'consensual assessment technique' (Amabile, 1983).

Hypothesis 2:

Based on general cultural values within a society, consistencies will underlie the assessments of judges (Child, 1970). People who have similar learning experiences within the domain of industrial design engineering, by class or education, will show more agreement in assessing both the aesthetic preference (Temme, 1983) and the level of creativity of the designs.

Hypothesis 3:

Judges with a high level of expertise in the domain will have more difficulty assessing products in terms of their fundamental attributes than judges with an intermediate level of expertise. An explanation for this could be that experts are over-involved in the product as an 'aesthetic whole' (Getzels & Csikszentmihalyi, 1976).

Hypothesis 4:

Although the concept of creativity is interrelated with other concepts, such as aesthetic appeal, appropriateness, and (technical) quality, it can be considered as a separate attribute. The difference between aesthetic appeal and creativity can be demonstrated by a discriminating variable, called the 'prototypicality' of the assessed design. The distance between the creativity of an object and the prototypical representation the judge has in mind, will be greater than between aesthetic appeal and that representation (Purcell, 1984). The idea, as in this situation, is that the more the observed product approximates the viewers mental representation the greater the chances are the product will be judged more attractive but at the same time less creative. Because we also expect a close relationship between creativity and attractiveness, the prototypical value can serve as a discriminating factor between them.

2.7 *Three studies into creativity*

In three studies the 'consensual assessment technique' of Amabile is applied to test the four hypotheses. All three studies were conducted at the School of Industrial Design Engineering at Delft University in The Netherlands. As products to be assessed, models designed by first-year students as part of their formal design courses were used. The variations between the three studies have mainly to do with differences in the number of assessment attributes, and in the expertise of the judges. In study 1 products are assessed by judges with different levels of expertise in design. In study 2 verbal reports of the design projects serve as the material to be assessed by a group of senior design students. Study 3 is partly a replication of study 1, but particular attention is paid to the relationship between creativity and prototypical value. Moreover, a homogeneous group of judges is selected from senior design student sample. The way in which the variables are operationalized are as follows:

1 In hypothesis 1 the agreement between observers (judges) is measured by coefficient alpha, represented in the equation (Nunnally, 1967; p. 196):

$$\frac{k}{k-1}\left(1-\frac{\sum \sigma_i^2}{\sigma_y^2}\right)$$

Where

$\sum \sigma_i^2$ = variances on the diagonal

σ_y^2 = sum of elements in the covariance matrix

k = number of judges

This coefficient gives a good approach for the analysis of between-design and within-design variance in ratings, taking into account the number of judges (Winer, 1971). Moreover, its use allows for a comparison with the studies of Amabile (1983).

2 The problem a subject experiences in judging objects on any attribute could be an indication of the internal consistency with which he is using that attribute. In other words, if a judge does not have any difficulty in assessing an attribute, then he will not be inclined to revise his opinion. On the other hand, much difficulty suggests much doubt, which can lead to inconsistency over repeated measures. The degree of difficulty can thus be used as a supporting measure concerning the reliability of the creativity assessment.

3 The influence of differences in expertise, as stated in hypotheses 2 and 3, will be determined by recruiting judges from three levels of expertise ranging from experienced design teachers within the same school to outsiders without any design experience at all.

4 An important issue in the studies will be the validity of the creativity concept. Therefore, other attributes will be used as assessment criteria. In order to compare the results with former studies some attributes will be derived from those studies, such as 'technical quality' and 'aesthetic preference'.

5 In accordance with a cognitive view on the judgement activity itself (e.g. Purcell, 1984) the relationship between the creativity and aesthetic preference attribute on the one hand and the 'prototypical value of the product' on the other hand will be analysed.

2.8 *Study I*

2.8.1 *Method*

Products

The data were gathered from the 1985 student population of the School of Industrial Design Engineering (IDE). A random sample of 60 (out of 200) first-year students was drawn. From this sample 16 students were removed because of deviant schooling background; i.e. they had already received an academic qualification in another discipline, while the remaining 44 students had just finished secondary education. All of them were enroled on the design course.

The first year design course consists of four projects in which students solve a design problem by making an artefact and by writing a process report. The third project was the only one in 1985 which was performed individually. Therefore it was selected to assess the creativity of the 44 students design products. In the project, half of the 60 students were given a brief to design a "public telephone booth", and the others to design a "computer cabinet". The timetable for this project covered 48 hours in total, 8 hours a week. The solution was to be modelled in coloured or plain cardboard of about 15 to 20 inch high. The models, 19 computer cabinets and 25 telephone booths, were photographed individually in two different positions and recorded on slides. These slides were used in this study. See figure 2.4 for some examples.

Judges

Three different groups of judges were used, varying in design expertise:

1 12 Students of the Mathematics Department from Delft University of Technology (DUT).
2 12 Senior students of the Industrial Design Engineering Department (IDE).
3 10 Design teachers (industrial designers) of the Industrial Design Engineering Department (IDE).

Only male subjects were selected. Judges of both student populations 1 and 2 were recruited by an announcement on billboards in both departments. As far as the maths group were concerned only first-year and second-year students were recruited, whereas the IDE-student judges were in their third year or above, having finished their first design course (3A). The only requirement of the design teachers was, that they were not involved in the first-year education programme, otherwise they may have possessed biased knowledge toward the products and possibly their creators. Only the student judges received a small reward.

Procedure

Each judge was asked to rate all 44 designs individually on seven attributes:
- *Creativity*; judges were asked to use their own definition (cf. Amabile, 1983).
- *Technical quality*; the extent to which a product meets the necessary technical requirements.
- *Attractiveness*; preference for the outward form.
- *Interest*; the extent to which the product arouses interest or fascinates.
- *Expressiveness*; the extent to which the product expresses its meaning.
- *Integrating capacity*; the extent to which the product integrates the underlying aspects of form, function and construction.
- *Goodness of example* (this term being used by Purcell, 1984); the extent to which the product is prototypical for its class of products.

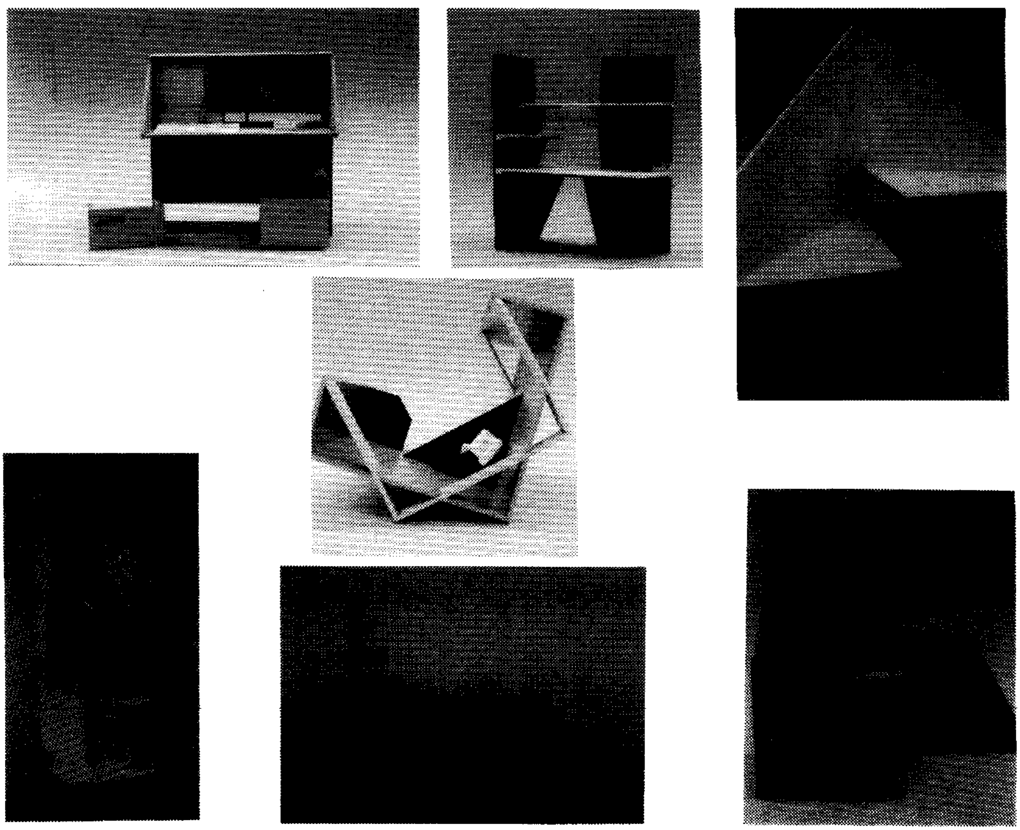

Figure 2.4 Examples of products assessed in study I

According to Purcell (1984) it would be possible to determine the departure of each product to one's own prototypical representation by the use of Likert scales. In order to exclude the influence of other attributes assessed, it was preferable always to start with the prototypicality attribute. In introducing the attribute named 'goodness of example' to the judges, extensive instruction was provided, based on the study by Purcell. The next part of the instruction is derived from Rosch and Mervis (1975, p. 588) with only minor variations:

> "With this attribute the question is what we have in mind in using a word that refers to a category. Just think for example of the word 'blue'. Close your eyes and imagine a true blue. Now imagine a navy blue, now a turquoise. Although you might still name the navy blue or the turquoise with the term blue, for you they are not as good examples of blue as the clear 'true' blue. In short, some blues are more blue than others. The same is true for other kinds of categories. Think of dogs. You all have some notion of what a 'real dog', a 'doggy dog' is. To me a Retriever or a German Shepherd is a very doggy dog while a Pekinese is a less doggy dog. Notice that this kind of judgement has nothing to do with how well you like the things; you can like a turquoise better than a true blue but still recognise that the colour you like is not a true blue. You may prefer to own a Pekinese without thinking that it is the breed that best represent what people mean by dogginess."

Subjects were told then (see also Purcell, 1984):

> " In this study you are asked to judge how **good an example of a category** various instances (cardboard models) of the categories (computer cabinets and telephone booths) are. You will be shown two slides of every model. You are to indicate how good an example of the category each model is by using the numbers 0 to 10. If you feel that a model is the best example of your image of a telephone booth or a computer cabinet you would use the number 10. If you feel that it is the worst example you would use a 0.
> Don't worry about why you feel something is or is not a good example of the category. And don't worry about whether it's just you or people in general who feel that way. Just mark it the way you personally perceive it."

As for the other attributes judges had to assess the products on a 10 point scale, with 10 being the most attractive, the most creative, of highest technical quality, etc. This scale was used because in the common educational setting grades are based on the same scale.
The instructions for all attributes were, together with the scales, included in a booklet. Each instruction ended with three statements of advice:

> "- Use if possible all numbers on the scale (i.e. 0 to 10). All gradations are possible. So, don't think of school grades, because you otherwise would not use the extremes of the scale.
> - Give a relative assessment, i.e. involve the judgements of other models after seeing them all.
> - Stick to the seqùence in which the slides are presented."

Two slides of each model from different angles were projected side by side, for 8 seconds. After presenting all 44 models subjects had to read the instruction concerning the attribute 'goodness of example'. Then again all models were shown and assessed, whereupon the next assessment attribute was presented showing again the 44 products, etc. The (slides of) models

were arranged in a different random order for each judge, as was the case with the attributes, except for 'goodness of example' which was always evaluated first.
A 10 point scale was also used for measuring the degree of difficulty in using the seven attributes as assessment criteria.

2.8.2 *Results*

Reliability

For the two products, computer cabinets and telephone booths, intercorrelations between each group of judges were measured. One product was designed by each student. The values, presented in table 2.1, show a difference between the two products: in general the values for the assessment of telephone booths are higher. This difference is not due to a greater variability in scores between the designs: for computer cabinets $\bar{x}_{teachers}$ = 4.34 and sd = 1.38; for telephone booths $\bar{x}_{teachers}$ = 5.55 and sd = 1.39. Although the values are not high, intercorrelations for creativity are, overall, slightly better than for the other attributes. These intercorrelations do not provide a correct estimation of the reliability of the assessment technique, i.e. of the correlation between the observed sum-scores and the 'true' scores of each group of judges for each attribute. A measure for this reliability can be understood as an expected correlation between each group of judges and a comparable group in the future. As mentioned before, coefficient alpha is suitable for this purpose.
On the basis of the observed correlations, estimates of the reliability of the measurement can be done.

Table 2.1 Average within-group intercorrelations on 7 assessment attributes, separate for the 2 products

	Computer cabinet			Telephone booth		
Attribute	IDE-teacher	IDE-student	Maths-student	IDE-teacher	IDE-student	Maths-student
Creativity	.28	.26	.23	.33	.36	.45
Prototypical value	.21	.21	.19	.33	.24	.46
Attractiveness	.17	.12	.18	.40	.34	.38
Interest	.18	.21	.15	.37	.33	.38
Technical quality	.24	.22	.31	.33	.25	.21
Expressiveness	.15	.08	.21	.36	.30	.34
Integrative capacity	.20	.04	.24	.42	.19	.40

Inter-rater reliability was calculated for each of the three groups of judges, again separate for the two product groups. As the reliability-coefficients show there is a high level of agreement on creativity within each group of judges irrespective of the product (see table 2.2). In nearly all other attributes there is greater variation between the scores of judges. The lowest values are measured for the attributes expressiveness and integrative capacity.

Table 2.2 Inter-rater reliability for 3 groups of judges on 7 assessment attributes

Attribute	Computer cabinet IDE-teacher	Computer cabinet IDE-student	Computer cabinet Maths-student	Telephone booth IDE-teacher	Telephone booth IDE-student	Telephone booth Maths-student
Creativity	.79	.81	.79	.79	.86	.88
Prototypical value	.71	.79	.74	.83	.80	.91
Attractiveness	.66	.66	.72	.86	.84	.89
Interest	.68	.76	.65	.84	.83	.87
Technical quality	.74	.79	.84	.84	.81	.74
Expressiveness	.66	.48	.76	.84	.81	.86
Integrative capacity	.72	.24	.77	.87	.74	.88

Support for the reliability in measuring creativity can be found in the degree of agreement between judgement groups on creativity and other measures.
In figure 2.5 this level of agreement is represented by graphs, firstly concerning IDE-teachers and IDE-students on the attributes of attractiveness and technical quality (fig. 2.5a) and secondly all judgement groups on creativity (fig. 2.5b).
The agreement in assessing creativity is higher than that for any other attribute, especially between the design teachers and the IDE senior students.

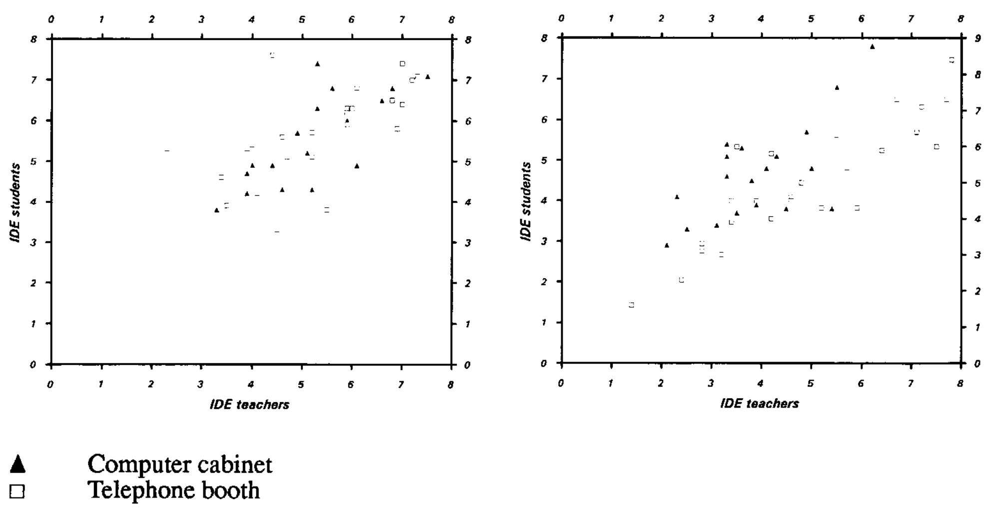

Figure 2.5a Correlation between IDE-teachers and IDE-students on attractiveness and technical quality

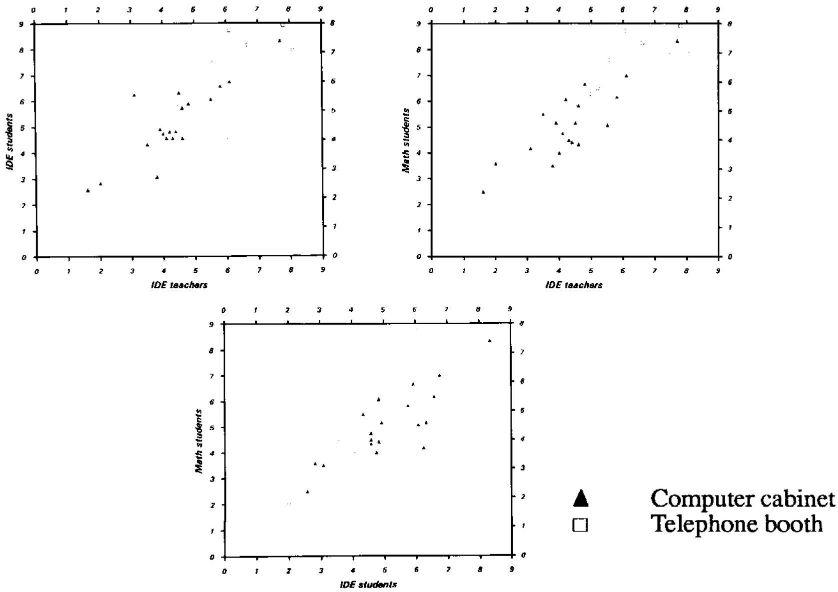

Figure 2.5b Correlation between IDE-teachers, IDE-students, and Maths-students on creativity

Difficulty of assessment

The difficulty a judge experiences in assessing objects on any attribute could be another indication of the internal consistency with which he is using that attribute.

Table 2.3 Average degree of difficulty in judging designs on various attributes

Attribute		IDE-teacher	IDE-student	Maths-student
Creativity	$\bar{x}$	3.90	3.08	2.00
	sd	*3.41*	*1.83*	*1.65*
Prototypical value	$\bar{x}$	4.00	5.00	4.25
	sd	*3.16*	*3.30*	*2.14*
Attractiveness	$\bar{x}$	2.90	2.00	1.33
	sd	*3.14*	*2.92*	*1.89*
Interest	$\bar{x}$	3.20	3.00	1.92
	sd	*3.39*	*2.56*	*1.62*
Technical quality	$\bar{x}$	5.00	5.42	5.50
	sd	*3.16*	*2.97*	*2.68*
Expressiveness	$\bar{x}$	5.30	6.58	7.75
	sd	*3.86*	*2.84*	*2.18*
Integrative capacity	$\bar{x}$	4.90	7.67	5.83
	sd	*3.90*	*2.10*	*3.24*

The relative ease with which products are assessed on creativity may suggest that this concept has some meaning. In table 2.3 the degree of difficulty in using each attribute as an assessment criterion is presented by means of average scores and standard deviations separate for each group of judges. Again, a 10-point scale was used, a low number indicating more ease in judging. As can be seen the judges do not have any trouble with the attributes attractiveness, interest and creativity.

Validity

Intercorrelations between the different attributes can shed some light on the question of validity (see table 2.4).

Table 2.4 Intercorrelations between attributes (average scores). On the right of the diagonal the coefficients for the telephone booth are presented, and on the left the coefficients for the computer cabinet. A = IDE teachers, B = IDE students and C = Maths students.

Telephone booth

Attribute		Crea.	Proto.	Attrac.	Inter.	Tech.	Express.	Integra.
Creativity	A	-	.64	.89	.92	.73	.84	.83
	B	-	.23	.76	.89	.13	.65	.70
	C	-	.36	.57	.85	.18	.45	.40
Prototype	A	.33	-	.87	.82	.85	.90	.88
	B	-.27	-	.63	.44	.37	.69	.58
	C	-.07	-	.78	.69	.50	.82	.86
Attractiveness	A	.78	.64	-	.96	.86	.96	.91
	B	.72	.00	-	.90	.60	.92	.92
	C	.24	.72	-	.84	.66	.95	.83
Interest	A	.89	.45	.89	-	.85	.95	.94
	B	.89	.00	.79	-	.38	.81	.82
	C	.65	.40	.69	-	.47	.77	.68
Technical quality	A	.08	.65	.55	.25	-	.87	.88
	B	-.34	.26	.04	.38	-	.57	.62
	C	-.34	.67	.63	.22	-	.70	.55
Expressiveness	A	.70	.50	.87	.86	.51	-	.94
	B	.45	-.09	.77	.45	.34	-	.86
	C	-.13	.72	.84	.45	.73	-	.88
Integrating capacity	A	.70	.66	.92	.80	.67	.91	-
	B	.50	.11	.66	.57	.22	.75	-
	C	-.04	.72	.84	.51	.62	.89	-

Computer cabinet

As the coefficients in table 2.4 show, creativity is most closely related to attractiveness and interest, while its correlation with prototypical value and technical quality is, on the whole, small. Secondly, looking at the design teachers, nearly all correlations between the attributes are high, especially when judging the telephone booth. These results confirm the conclusion of Getzels & Csikszentmihalyi (1976) that design experts are less able to distinguish between the different attributes involved.

The attributes 'expressiveness' and 'integrating capacity' give a rather obscure picture. The different groups of judges seem to interpret these attributes in a different way.

Factor analysis

Factor analysis indicates the structure that underlies the assessment attributes. Any of the performed analyses, separate for group of judges and type of product, yield a two-factor solution. Factor loadings, after Varimax rotation, are presented in appendix I. Factor solutions for the assessment of computer cabinets are illustrated in figure 2.6.

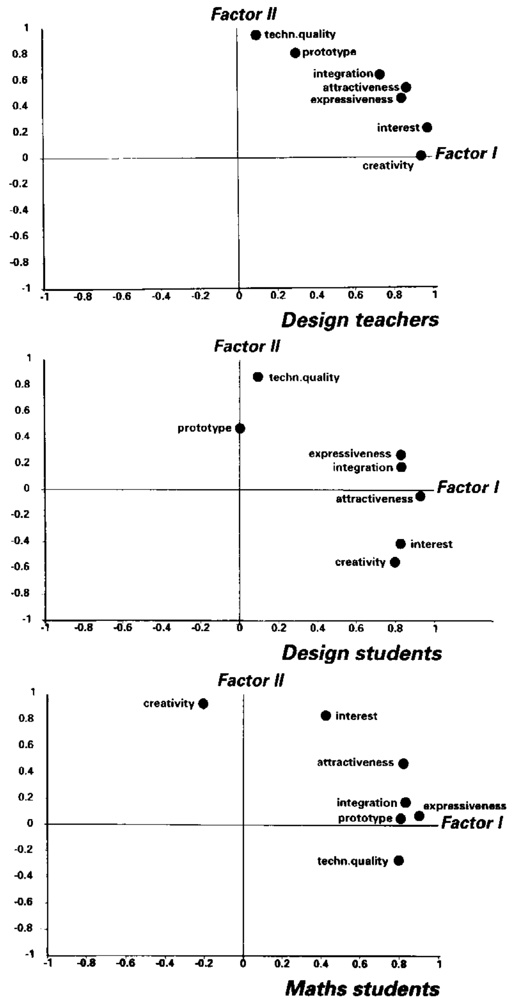

Figure 2.6 Rotated factor matrices for each group of judges; computer cabinets

As can be seen from the figures above one of the two factors is the creativity factor, while the other factor is determined by the technical quality attribute. All other attributes lie in-between. Factor scores for design teachers and IDE students are most closely associated, while the factor solution for Maths students differs slightly. This difference is shown mainly through the position of the attractiveness attribute in relation to that of prototypicality.

Test attributes and official marks

A comparison is made between the scores on each attribute and the official marks of design teachers given for the same products. In table 2.5 the correlations between both measures are presented. The low correlation with creativity is striking, while technical quality apparently has considerable impact.

Table 2.5 (Rank-)correlations between marks for design course and assessment attributes; study I

Attribute	Mark (comput.cab.)	Mark (teleph.booth)
Creativity	.02	.30
Prototypical value	.37	.53
Attractiveness	.24	.42
Interest	.08	.43
Technical quality	.52	.61
Expressiveness	.37	.52
Integrative capacity	.37	.53

Prototype view and creativity

The relative distances between the assessment attributes, appearing in the factor solutions, strengthen the hypothesized relationship between the prototypical, attractiveness and creativity values. The prototypicality of the judged object appears to be a discriminating factor between the attractiveness of that object and its creativity. Another method for testing the hypothesis is by using the statistical technique of Multidimensional Scaling (MDS). In the INDSCAL-model (Caroll & Chang, 1970) similarities between all pairs of stimuli for each judgement attribute are calculated, next a common underlying configuration of stimulus points is produced throughout a number of dimensionalities. In the analysis here the dimensionalities are the three groups of judges and the seven assessment attributes. In fig. 2.7a and 2.7b the configuration of the 'computer cabinet' models and the 'telephone booth' models respectively are shown. Again, the configurations of the assessment attributes are congruous, in that the distance between the creativity and prototype value is great, while the gap between attractiveness and prototypical value is slight. The position of the three groups of judges indicates the close relationship between the two IDE-groups and the inharmonious Maths group.

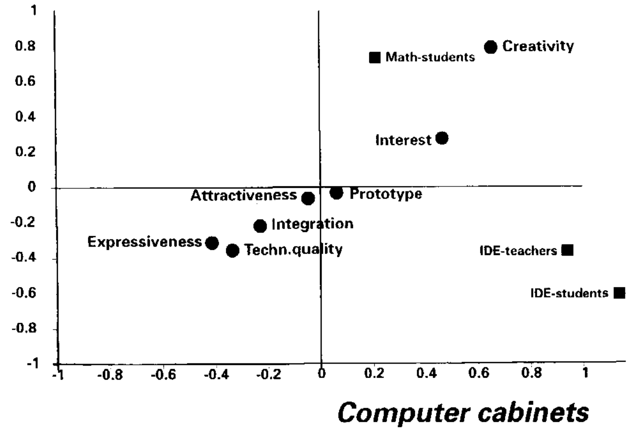

Figure 2.7a Configuration of assessment attributes and judgment groups, based on INDSCAL-S; computer cabinets

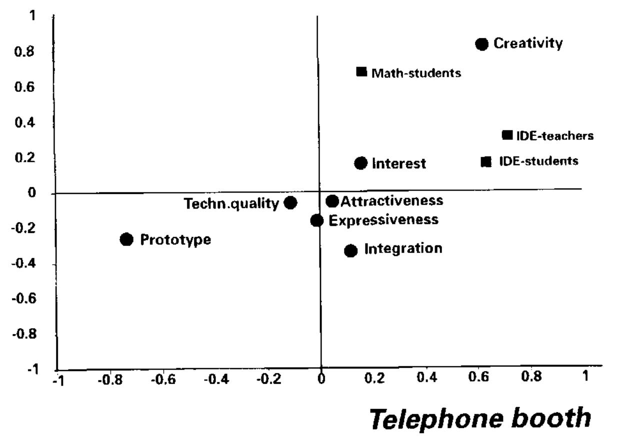

Figure 2.7b Configuration of assessment attributes and judgment groups, based on INDSCAL-S; telephone booth

2.8.3 *Discussion*

The reliability coefficients on creativity are in the same direction as in earlier studies. The agreement between the design teachers and the senior IDE-students is further proof of this result. As to the judgement of IDE-teachers, the high intercorrelations between the assessment

attributes confirm the findings of Getzels & Csikszentmihalyi (1976). The authors assume that experts are much too involved in objects as aesthetic wholes and therefore consider differentiation between attributes as spurious abstractions. The slightly different position of maths students is possibly due to the fact that they do not share the experiences of the other two groups.

As to the validity question, firstly the relationship of creativity with other attributes is of interest. The results make clear that 'technical quality' and 'creativity' are in this study two separate factors. On the other hand, there is a close relationship between creativity and the two aesthetic attributes, interest and attractiveness. However they are separate attributes as is shown by a third discriminating attribute, the prototypical value of an object. As was expected the distance between creativity and prototypicality is naturally larger than the distance between the aesthetic attributes and prototypicality; i.e. an object which is prototypical to an observer will generally receive a low creativity rating. The hypothesis concerning the identity of creativity as a separate attribute seems partly to be confirmed. Nevertheless, in the case of the judgment by IDE-teachers the correlation between prototypical value and creativity is, unfittingly, rather high. Further research on this topic is described in one of the following studies.

Interesting is the close relationship between technical quality and the prototypical value. Designs that are prototypical, and presumably close to acknowledged designs, are assessed to be of higher technical quality than designs remote from the prototype.

The correlation between our assessment attributes and the official marks in design education does not clarify the validity issue. Conversely, if the measurement in this study is valid, the conclusion could be drawn that in the official assessment of students design quality much attention is paid to technical aspects at the expense of creativity.

Finally, the ease with which judges use the creativity attribute in assessing models of first-year students can also count for a valid measurement, in that at least we can expect 'face validity'.

Before replicating part of this study the assessment technique will be examined while products of a different kind are judged.

2.9 *Study II*

A further analysis of the creativity attribute as a valid criterion was made by giving judges comparable products from the same students in study I. Within the design course students produce not only an artifact, like the cardboard model, but also a verbal report. In this report information is presented concerning design requirements, technical aspects, calculations, choices of material and so on. The report also contains a rendering of the model itself. It was questioned whether the scores for creativity on the models should correlate with those on the verbal reports.

2.9.1 *Method*

Products

On this occasion the products were 44 verbal reports written by the same first-year students whose products were used in study I. The report and the product were produced for the same design project, with the same submitting deadline.
Because of the impracticability for every judge to assess extensively all 44 reports on all seven attributes from study I, a less time-consuming experimental design was chosen. Firstly, the number of attributes was restricted to five: the attributes 'interest' and 'prototypical value' were removed. Secondly, in order to restrict the number of reports for each judge without a major loss of information, an analysis technique known as 'incomplete randomized block design' was chosen (Davies, 1978). In table 2.6 an example of the design is presented. Missing values are replaced with estimates based on the average scores of 126 out of 133 observations; using this method powerful statistical measures could be applied. Each judge assessed only 13 or 14 reports, while each report was assessed by 7 judges.

Judges

The judges were 22 senior male IDE-students with schooling requirements pertaining to those of study I, although not involved as judges in that study.

Procedure

The assessment was done individually. At the start of the session the experimenter assigned to the judges a complete set of reports with the instruction to go through each of them. Moreover, the judges were told that after they'd finish reading all 13 or 14 reports they should be assessed on various attributes, the attributes were not revealed. The judges then had to gesticulate in order to receive their first assessment attribute including the 10-point scales for each report. After the judges had assessed all reports on the present attribute, the form was removed and the next attribute provided. The same procedure was followed until all five attributes were assessed. On each attribute the instructions were consistent with study I.

There was a time limit of 2½ hours imposed. Reports were randomly assigned to judges, except that each judge received reports on only one groups of products, either the computer cabinets or telephone booths.

Table 2.6 Incomplete randomized block design for assigning reports (on telephone booth)

	Judges												
Teleph.booth	1	2	3	4	5	6	7	8	9	10	11	12	13
1 / 2	x	x	x	x	x	x	x						
3 / 4		x	x	x	x	x	x	x					
5 / 6			x	x	x	x	x	x	x				
7 / 8				x	x	x	x	x	x	x			
9 / 10					x	x	x	x	x	x	x		
11 / 12						x	x	x	x	x	x	x	
13 / 14							x	x	x	x	x	x	x
15 / 16	x							x	x	x	x	x	x
17 / 18	x	x							x	x	x	x	x
19 / 20	x	x	x							x	x	x	x
21 / 22	x	x	x	x							x	x	x
23 / 24	x	x	x	x	x							x	x
25	x	x	x	x	x	x							x

2.9.2 *Results*

Average intercorrelations between judges are presented in table 2.7. Because of the use of the incomplete block-design α-coefficients, as reliability measures, are difficult to estimate. The values concerning creativity are different for the two types of products judged. In judging computer cabinets no agreement exists at all. On the other hand, the high values for technical quality are striking.

Table 2.7 Average intercorrelations between judges in assessing reports (computer cab.: N = 10; teleph. booth: N = 13)

Attribute	computer cabinet	telephone booth
Creativity	.08	.31
Attractiveness	.32	.43
Technical quality	.51	.49
Expressiveness	.13	.32
Integration	.36	.35

The correlations between creativity and the other attributes are between .57 and .74 for reports on the 'computer cabinet' and between .70 and .80 as far as the 'telephone booth' is concerned.

Other relevant data with respect to the evaluation of the reliability and validity of creativity measurement are the correlations between product and report.

Because creativity assessments for both models and reports by the same group of judges are not available, correlations between the different groups must be leant on. Comparing the creativity scores for models of IDE-teachers, IDE-students and Maths-students respectively with the creativity scores for reports, the correlations vary from -.16 to .12 (computer cabinet) and from .22 to .40 (telephone booth).

2.9.3 *Discussion*

Assessment of creativity based on verbal reports does not provide reliable results. This finding is not at all bizarre when the content of the report is considered. Students are asked to transcribe and highlight their own design process as well as the technical details of the design solution chosen. Presentations of ideas through drawings, which are also included, are generally of poor quality because halfway the course first-year students tend to lack adequate drawing skills. The relatively high average intercorrelation on technical quality confirms this statement. Additional support for this can be found in the preliminary conclusion of study I, i.e. the marks in the first-year design course show the same emphasis on the attribute of technical quality. In their grading task teachers are too heavily dependent on the same verbal reports.

2.10 *Study III*

The third study focuses on further elaboration of the results from study I. Firstly, by replicating study I reliability of the assessment techniques can be examined, and the relationship found between creativity and other attributes tested. However, the method followed in study III differs in two respects. On one hand, two assessment attributes, expressiveness and integrative capacity, are removed, because of their doubtful reliability and validity. On the other, only one group of judges is involved. For reasons mentioned in the discussion of study I only senior IDE-students have been selected. This group proved to be equal to the judgement task in comparison to IDE-teachers. Moreover, they were better able than the IDE-teachers to differentiate between the various attributes. This further improvement in judge selection, by increasing homogeneity, it was thought would perhaps lead to different results.
A second objective of study III was to validate the assessment technique by investigating the 'nomological network' around the creativity concept (De Groot, 1961). In order to analyse the association between the creativity and prototypical value a new method was used to determine the mental representation of the relevant object. Moreover, efforts were made to identify what product features contribute to its creativity. For this purpose judges were both interviewed and asked to fill in a 'semantic scale' for a number of products. Besemer & O'Quin (1986) developed a Creative Product Semantic Scale (CPSS), based on a theoretical model in which three conceptual attributes are proposed (p.114): "*Novelty* (newness of processes, materials and design), *Resolution* (functionality, usefulness, workableness of the product), and *Elaboration and Synthesis* (the stylistic attributes of the finished product)." For each of the attributes a great number of bipolar subscales were developed, these totalled 70. This CPSS was used in the study. In appendix IIa the list of bipolar adjectives is reported. Because, after translation into Dutch, two subscales were nearly identical, one subscale from the original list was removed.

2.10.1 *Method*

Products

Data were gathered from the 1987 student population of the School of Industrial Design Engineering (IDE). The first-year population of 240 freshmen is, through the design course, divided in 4 groups of 60 students. From two groups 55 subjects were selected randomly. The first-year design course in 1987 consisted of five design projects, the first two of which were performed in groups. From the other three individually undertaken projects the models made by students were used as stimuli in the study.
The first model was again a telephone booth, made as the third project of the design course. Through slide photography each of the cardboard models was recorded from two different angles.
The second model was a cardboard shop-window display, of this only one slide was taken.

The third and final product was a presentation drawing of a drill holder. On behalf of the assessment procedure one slide was photographed of the presentation drawing and another of the technical drawing made of the same product.
See figure 2.8 for some examples of the products.

Judges

For reasons mentioned in the discussion of study I judges were only selected from the senior IDE-student population. In order to raise the homogeneity of the judgement group only male fourth-year students were selected with high marks for all design courses in the preceding years. By this, a homogeneous sample of 10 judges was obtained.

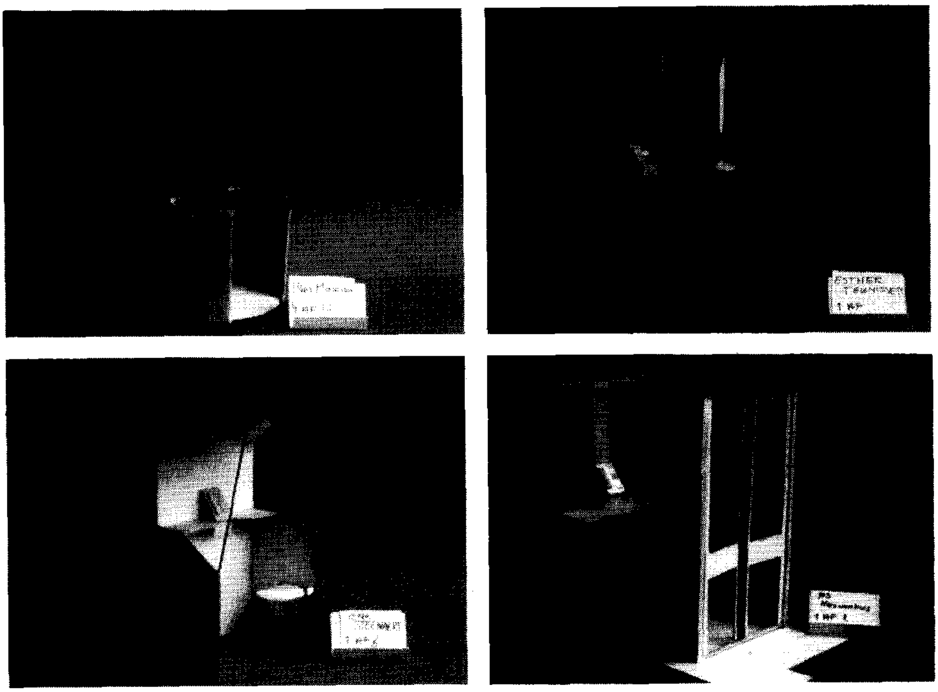

Figure 2.8 Examples of products assessed in study III

Questionnaire

A translated version of the Besemer & O'Quin's Creative Product Semantic Scale (CPSS) was used in this study. The Dutch version of the scale consisted of a list of 69 bipolar 7-points subscales. For every product assessed the subject filled in the whole list. The list is presented in appendix IIa.

Procedure

The judgment task was performed throughout two sessions. In the first session 55 models of the telephone booth were judged. The assessment attributes were: creativity, prototypical value, attractiveness, interest, and technical quality. The same instructions from study I were used, except that the concept of prototypicality was no longer defined by the words 'goodness of example' but by 'prototypical value'. Moreover, the way it was measured differed. In study I after presenting the slides of the products judges had to assess how much each product differed from their own mental representation, i.e. prototype. In study III before the design products were presented, each judge was asked to sketch his prototype of a telephone booth on a piece of blank A4-paper. By this method it was expected that a more reliable reproduction of the judges prototype could be determined. In figure 2.9 examples of these sketches are presented.
Next, as in study I, they had to judge all 55 designs for prototypical value. Two slides of each design from different camera angles were projected side by side, for 8 seconds. The same procedure was repeated for the other attributes.

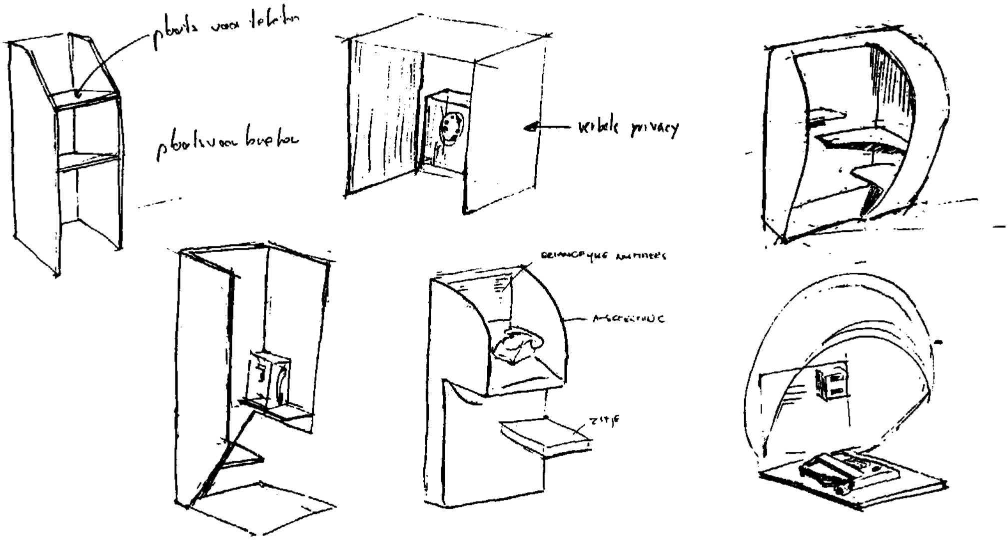

Figure 2.9 Sketches of prototypical representations of telephone booths

The order in which the attributes were assessed was fixed: prototypical value, creativity, technical quality and attractiveness. The random sequence of slides was changed every time the slides were assessed on another attribute. Each judge undertook the task individually, as for previous studies, rating the designs on a 10-point scale. The instructions were also the same as before.

In the second session, 10 months later, the same judges were asked to perform four assessment tasks:

1 Assessment of the 35 shop-window displays on three attributes: creativity, technical quality, and attractiveness. The sequence of attributes was fixed, but that of the models varied between subjects. Slides of the prototypes were used.
2 A semi pair-comparison analysis of two high creative and two low creative objects from the first session (telephone booth), by means of an interview with a judge. While showing slides of a high and a low creative object side by side, judges were asked to explain extensively why one was creative and the other was not. This procedure was then repeated with another pair of products. The experimenter only interrupted the judge to summarize what had been said. The protocols were recorded on tape and afterwards reproduced completely in a verbal report. An example of the comments by one subject is presented in appendix IIb.
3 Assessment of the 30 drill-holders on three attributes: creativity, technical quality, and attractiveness. The designs were presented on slides, two for each design: a rendering (presentation drawing) of the design, and a technical drawing. By adding a second drawing an attempt was made to improve the assessment of technical quality, and thus raise the reliability of this attribute. The sequence of attributes was fixed, but for the models varied between subjects.
4 The same products used in the pair-comparison task were judged on the CPSS, the aforementioned semantic scale. This scale contains a series of 69 7-point subscales. Ensuing the task, the aim of the scale was explained to the subject followed by the first slide. After completion of the list, the next slide was presented and a new list with the same scales was supplied. This procedure was repeated for all four products (on slides).

2.10.2 *Results*

Reliability

Results of the assessment of telephone units, displays and drill holders are presented first. In table 2.8 the average intercorrelations between the 10 judges and the reliability coefficients (α) are illustrated.
In all three measurements the average intercorrelation for creativity is higher than for any other attribute. In comparison with study I this result is substantially improved. Consequently the reliability of the creativity measurement, as defined by coefficient α, is high.

Table 2.8 Average intercorrelations between judges, and coefficient α's

Attribute	Telephone booth r	Telephone booth α	Display r	Display α	Drill holder r	Drill holder α
Creativity	.48	.89	.57	.93	.49	.90
Attractiveness	.38	.86	.42	.88	.41	.85
Interest	.44	.89	-	-	-	-
Technical quality	.33	.84	.28	.80	.34	.82
Prototypicality	.18	.69	-	-	-	-

Validity

Looking at the relationship between the various attributes, creativity, as expected, is closely related to interest and attractiveness, while it correlates poorly with prototypical value and technical quality.

In table 2.9 (a) and (b) correlations between attributes are presented for the three products measured. The results indeed confirm the findings of the previous study. The hypothesis concerning the negative or zero correlation between creativity and prototypical value is supported.

Table 2.9a Correlations between attributes in assessing telephone booths

Telephone booth Attribute	Crea.	Attract.	Inter.	Techn.	Prototy.
Creativity	-				
Attractiveness	.70	-			
Interest	.86	.87	-		
Technical quality	.05	.56	.33	-	
Prototypicality	-.04	.16	.09	.34	-

Table 2.9b Separate correlations between attributes, for the display and drill holder

Attribute	Display Crea.	Display Attr.	Display Tech.	Drill holder Crea.	Drill holder Attr.	Drill holder Tech.
Creativity	-			-		
Attractiveness	.87	-		.87	-	
Technical quality	-.04	.32	-	.79	.83	-

Figure 2.10 shows the inter-relations based on factor analysis on the assessment scores of the telephone booths. The factor configuration looks very much like the aforementioned configurations in study I. In appendix I factor loadings are presented.

Oral judgment

In an interview the 10 judges were asked to verbalize the differences between pair-wise presented high- and low-creative products (telephone booths). An example of their comments is included in appendix IIb.
Because of the agreement between the judges statements it was possible to classify them into five separate categories. In table 2.10 a selection of encoded data is presented.

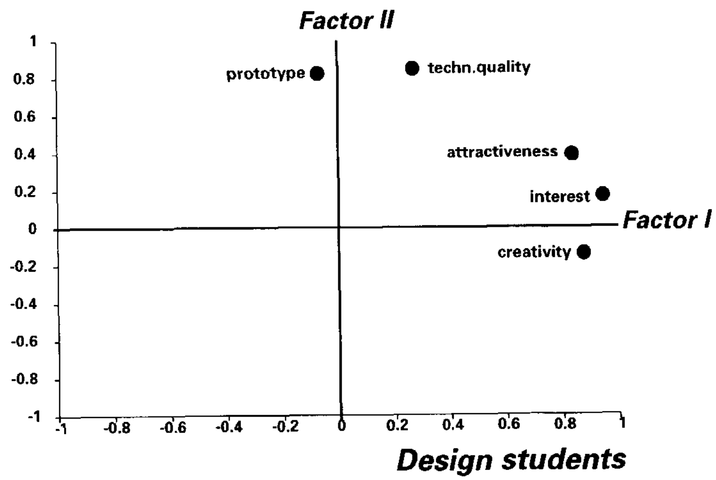

Figure 2.10 Factor analysis on the 'telephone booth' assessment

The five categories include:
- Expectation pattern:
  Judges apparently compare the presented unknown product with a representation of the product they already have in mind. Unexpected products or elements of products have a greater chance to be assessed as creative.
- Integration of various relevant attributes:
  The added value of the design is dependent on successful synthesis. In low creative products, components are stuck together, without any feeling for interdependence or wholeness. Imagery is important.
- Form and function:
  Creativity should not only be caught in general phrases but also through specific characteristics.

- Impact on the observer:
  A creative design triggers attention and fantasy.
- Commitment of the designer (Weisberg, 1988).
  The extent to which the designer felt 'challenged' by the design task. This attitude is demonstrated by: searching activities for new ideas and forms, facing difficulties and taking risks.

Most of the categories can be described generally, and are applicable to any domain. On the other hand, the 'integration' category together with the 'form and function' category seem more domain-specific. Compared with the other findings the 'expectation pattern' indicates again a relationship between the creativity and prototypical value.

Table 2.10 Interview statements on 2 high- and 2 low-creative products from 10 judges: a selection; k = total number of responses within the category.

High product creativity	Low product creativity
<u>Expectation pattern</u> (k = 11) • The designer made a great stride forward. • At first sight the design is unknown, different from existing solutions. • Let oneself go from the box idea. • The point of reference plays an important role. <u>Integration of various dimensions</u> (k = 16) • The design gives the feeling that the designer reflected on the function in relation to the implications of using a telephone. It asks for imagination. • Only if elements are integrated (shape, function, association, colour, situation), an original idea is possible. • The structure determines the creativity of the design in that the concept itself must be good. • The choice of a tube frame together with transparant synthetic material yields a very good match. <u>Form and function</u> (k = 29) • You have to draw a cylinder three-dimensionally, or to manipulate simple models of it. • The open structure together with the round shape is appealing. The design is fragile, refined. The colour corresponds to modern design. • The material is exploited fully. Tubes are partly curved, partly not. They do not serve only for supporting-section, but also for aesthetical embellishment. • Form details are balanced. The emphasis on some of these details is chosen deliberately. • The visual emphasis is toward the top. Hence, the design appears more dynamic. • The designer played with forms, with space by applying transparant areas. It seems to float through space. *<u>Table continued</u>*	<u>Expectation pattern</u> (k = 16) • The design comes up to one's expectations: a box in which to telephone. • It cannot be distinguished from existing boothes. It does not add anything. • If you imagine a telephone booth, you think of a heavy construction. • A straightforward design: solid where you expext it, transparant where you expect it • Originated from a old-fashioned, conventional train of thought. <u>Integration of various dimensions</u> (k = 12) • All elements are there: a telephone, a top, a seat. It will function very well, but it is not creative. Everything is simply stuck together. • Shapes are still unconnected. They must be integrated. In other words, the design appears still in it's infancy. • The function of this enclosure/ of the colour is unclear. The designer did not reflect upon the act of telephoning. • Here the designer chose very thick material, while at the same time he realized the booth had to be made transparant by using glass. The materials are not combined effectively. <u>Form and function</u> (k = 18) • The square shape is two-dimensional. It is a 'drawing-table design'. • When people seek solutions for protection, they build a square, a box. Working with straight lines is the fastest way. Thinking in terms of a box is not very creative. • The material is hardly exploited. The designer applied standard elements. It remains a semi-manufactured article. • The visual emphasis of this booth is toward the ground. due to the designs lower half solidity. It is obvious that one board up the bottom. Even the glass elements cannot change the static impression.

Table 2.10 - continued

High product creativity	Low product creativity
Impact on the observer (k=27) • The designer added value to the design by deliberately using associations. For example big shells for the ear-piece corresponding to a part of the activity. • The design stimulates fantasy. It evokes tension and emotion because its unexpexted image. It holds attention for a while.	Impact on the observer (k=17) • The design suggests a dug-out, a tram-shelter, the entrance of a big building, but it does not speak the language of the telephone and of the activity itself. • The design does not fascinate. It is boring, like looking at a white wall. Among so many visual impressions this is one you immediately forget.
Designer's commitment (k=7) • The designer searched for new forms. He spares no pains to come up with an attractive design. He takes risks in that it is uncertain if the result is functional and satisfies the client. • The designer has considered the problem of being original, the technical ingredients given; he is facing the difficulties like the connection of a curved surface on a cylinder, etcetera.	Designer's commitment (k=7) • The designer keeps on the easiest side. • Both in the concept and detail, nothing is searched for. Only minimum requirements are met. • The designer only tried to polish the primitive form, what is not creative.

Creative Product Semantic Scale

Finally, the same two high-creative and two low-creative products are assessed by the 10 judges through the Creative Product Semantic Scale, a questionnaire with a considerable number of attributes. The average scores for each product are presented in appendix IIa. Scores can range from 1 to 7. For an impression of the extent to which the attributes discriminate between high and low creative products in table 2.11 only attributes are taken into account, if the average scores on either both high creative products or both low creative products are $\bar{x} \leq 2.5$ or $\bar{x} \geq 5.5$ and the standard deviation sd < 1.0. Both high and low creative products are characterized mainly by the 'originality' dimension.
Gradual differences between the two high creative products are observed especially within the 'elaboration and synthesis' dimension, i.e. the product with the highest PCR is evaluated more charming, elegant, attractive, well-made. Moreover this product is also described as valuable, appropriate and feasible. There is also a gradual difference between the two products with a low PCR; one of the products is judged as more functional, feasible, usable and durable.
In general, the results do not add further details to the information already gathered from the interviews.

2.10.3 *Discussion*

The reliability of the consensual assessment technique in study III was again high. The results confirm the conclusions of the first study. In all three sessions, judging telephone booths, shop-window displays and drill holders, the agreement between the 10 judges is substantial. Also, the selection of a more homogeneous group of judges - senior male students from the

same year with high design marks - seemingly increases agreement, as was suggested by Amabile (1982).

Table 2.11 Attributes from the Creative Product Semantic Scale with an average score of $\bar{x} \leq 2.5$ or $\bar{x} \geq 5.5$ and sd < 1.0 on either both high PCR (product creativity rating) and/or both low PCR products

Design creativity		Design creativity	
High PCR	Low PCR	High PCR	Low PCR
Novelty		*Germinal*	
Original			warmed over
exciting	dull		average
	bland	radical	old hat
fresh	overused		
eccentric	conventional		
new	old	**Resolution**	
novel	predictable	*Useful*	
unusual			operable
unique	ordinary		
original	commonplace	**Elaboration and**	
		synthesis	
Surprising		*Elegant*	
startling	stale		unattractive
surprising	customary		
astonishing	commonplace	*Complex*	
	common		plain
	ordinary	interesting	boring

As in study I the agreement between judges on other attributes is lower in all three sessions. Again, there is a close relationship between creativity and the aesthetical attributes attractiveness and interest. Nevertheless, the assumption that creativity is a separate construct which can be distinguished from adjacent constructs is adhered to. The aesthetic attributes can be derived partly from the variable 'prototypical value', which discriminates between creativity and attractiveness. Sketching one's own internal representation before surveying the series of designs to be judged, was a useful way of measuring the influence this representation had in assessing other attributes.

When people judged the creativity of products they really seem to compare the object to be judged with their internal object representation, their prototype. The expected low correlation between prototypical value and creativity is indeed found in this study, while the correlation between this value and attractiveness is higher. However, the hypothesis regarding the close relationship between prototypical value and aesthetic appeal (Purcell, 1984) is not confirmed.

In two of the three sessions in study III the correlation between creativity and technical quality is low, as was found in study I. However, in judging drill holders this correlation is unexpectedly higher. In this particular session the technical drawings of the designs were also presented on slides. It follows then that in offering explicit technical information the judge may be better able to assess the technical quality of the product, and thus its impact on creativity. Nevertheless, even in this session the agreement on this attribute is low.

For a further analysis of the underlying aspects of creativity, verbal descriptions of objects were valuable. The pair-comparison of low creative and high creative designs provided extra information on what is understood by creativity. The aspects mentioned form a mixture of domain-specific and general elements. Firstly, the *expectation pattern* judges have is mentioned by all of them. It confirms the finding that people use their internal representation of the object as a frame of reference. Secondly, the extent to which the designer succeeds in *integrating* different design 'dimensions', like form, function and use, is manifested in the design itself. The protocols of the interviews show, that judges agree that integration leads to higher creativity. Thirdly, also *styling* seems to contribute further to the creativity of the design. Judges identify the use of certain techniques, by which objects look 'dynamic', 'fragile', and 'balanced', three adjectives with a positive bias. The *impact* of the design on the observer, a fourth aspect, can thus be manipulated by the designer if he is skilled in using such techniques. The last aspect mentioned is the *commitment* of the designer, it seems astonishing that judges can derive this by simply looking at the designs presented. All these aspects show, it is believed, that judges are very capable of defining what they understand by creativity. Moreover, their definitions, which are generally concordant, show that creativity differs from adjacent concepts.

Finally, the results of the responses to the Creative Product Semantic Scale (CPSS) of Besemer & O'Quin (1986) show at first sight the same trend as the pair-comparison. However, the Scale does not provide any detailed information as to the domain of designing. The attributes measured by the CPSS are limited and only superficial.

2.11 *General discussion*

The study into creativity, as described here, began within the context of industrial design engineering. The need for a criterion in order to evaluate the quality of the design process gave rise to the search for a operationally defined concept of creativity. The assumptions in the study were: (1) The concept of creativity is only meaningful within the context of the domain at issue. (2) A product approach in measuring creativity is most appropriate in giving reliable and valid assessment. The concept, as defined here, intended only to include product design. Although this domain relates much more broadly than to simply artifact design, most of the empirical data gathered were derived from the assessment of artifacts. (3) Creativity is conceived to be a culturally defined concept; therefore it is a relative measure.
Replication here of the research by Amabile (1983), using her 'consensual assessment technique' confirms that creativity can be measured reliably. Inter-rater reliability is high, even between judges who are unfamiliar with the domain. Also, if the homogeneity within the group of judges increases, the reliability coefficient too increases. As expected, people who had more common experiences within the domain of industrial design engineering, in this case by education, showed more agreement. On the other hand, experts within the domain, like design teachers, had difficulty in differentiating between the assessment

attributes. As suggested by Getzels & Csikszentmihalyi (1976), these experts are much too involved in the objects as aesthetic wholes to achieve consistent assessment-levels.
A somewhat contradictory conclusion is that assessment of creativity, based on only verbal reports, does not provide very reliable results. However, the aim of these technical reports is to provide the teacher with insight into the 'logical' (instead of chronological) process of steps taken, and more especially into the technical details of the design. This was confirmed by the uniquely consistent assessment of technical quality.
Looking more closely to the phenomenon of the high agreement between judges in relation to their homogeneity regarding their common experiences, the data suggest that creativity is really a unique attribute or construct that can validly be distinguished from other attributes. To answer the validity question the creativity concept was valued in relation to other adjacent concepts such as attractiveness, interest, and technical quality. In the studies, previous findings were confirmed. The relationship between creativity and the two aesthetical attributes was close, while technical quality varied significantly. Nevertheless the assumption that creativity can be distinguished from the aesthetic attributes is made. This assumption is based on the measurement of what the observer believes is prototypical with regard to the object he/she is assessing. The internal representation serves as a 'default value', to which new information is compared. The 'prototypicality' of an object, the distance between the object and the observers internal representation, appeared to discriminate between the creativity and aesthetical attributes. However, the theory of Purcell (1984), that the more the observed object is prototypical for the observer, the more attractive the object will be judged, was not confirmed. The correlations between prototypicality and both aesthetical attributes are rather low. Further research concerning in just these interrelations would appear valuable.

These studies also show that elements of the design process are reflected in the design itself. When judges are asked to verbalize about the underlying aspects of creativity, they refer to the integration of various design dimensions like form and function, about techniques of styling and elaboration of the design, and about the committment of the designer as manifested by his willingness to search for new solutions, and to take risks. As a consequence parts of these aspects are related to the learning process, and thus can be improved. These aspects lead to object-related qualities with a certain impact on the observer. Of course, important in the assessment of creativity then becomes the extent to which the object deviates from the observers expectation pattern.

Creativity is not conceived of as an elusive phenomenon. The product definition was chosen here to develop a criterion for evaluating the design process. Because of its relative nature, the definition only allows for statements regarding the products assessed. Therefore, as far as the consensual assessment technique is used for instrumental purposes, for example as a means for evaluating the design process or assessing student results, Amabile's technique is very useful.

The next step is to focus on the design process itself, analysing the factors which contribute to an optimum strategy and lead to high quality products. Within the traditional bounds of

cognitive psychology focus will be fixed on the information processing during this design process. Because designing is a form of human problem solving and skill acquisition that seems rather similar to problem solving in other complex, knowledge-rich domains, the descriptive models based on these other subject domains can probably be applied. In studying the design process generation of a new and more refined model of the subsequent stages in the process is not of interest here, rather the investigation of what knowledge and skills regarding the designer are important or necessary in solving a design problem. The first area in which to study the role of design knowledge is the context of formal design education where first-year students can be considered as novice designers. Next, through the participation of students from the School of Industrial Design Engineering, the novice-expert paradigm is analysed in a laboratory setting on the basis of protocol studies.

Chapter 3 The knowledge base of the designer: knowledge acquisition by design students [2]

3.1 *Introduction*

In the chapters 3 and 4 two different research methods are presented to study the role of design knowledge in relation to the creativity of the design solution. The first method is based on the analysis of retrospective 'learner reports', which were written by first-year students through the design course. The selection of this method was a consequence of one of the aims of the study in this chapter, i.e. to study the design process within a standard design curriculum. A knowledge classification technique is introduced and tested on usability and validity. The second method makes use of a laboratory setting in which concurrent verbal reports from the problem solver by way of 'thinking aloud' protocols are gathered. While in this chapter the theoretical assumptions regarding cognitive theory are emphasized, in chapter 4 methodological aspects regarding techniques of eliciting problem solvers knowledge are dealt with.
In both chapters attention is focused on the design process and in particular what role the designers knowledge plays. With the term *knowledge* is refered, according to Alexander et al. (1991), to:

> "...an individual's personal stock of information, skills, experiences, beliefs and memories" (Alexander, et al., 1991, p. 317).

The concept of *information* refers to the 'input'side, before it is processed by a person.
There are several reasons which instigated this investigation. Firstly, a new paradigm in design methodology is the idea that for a fruitful design theory we badly need a description of the design process in terms of cognitive and computational models (Dixon, 1988). Secondly, research in cognitive psychology over the last two decades has made clear that knowledge is of major relevance in understanding problem solving (Kovotsky and Simon, 1990). Thirdly, the work on knowledge-based problem solving supports the view that expert problem solving depends primarily on having appropriate domain-specific knowledge and not on any unusual intellectual abilities (Anderson, 1987; Elio & Scharf, 1990). *Domain-specific*

[2] I am grateful for the cooperation of Kees Venselaar in conducting the studies and performing part of the analysis

knowledge is understood as knowledge about a specific field of study, referring here to basic and design knowledge applied in industrial design engineering.
An obvious and potentially fruitful environment for studying the development of knowledge acquisition in design engineering is a design school. Solving design problems is of primary importance in design education. Therefore, the nature of knowledge that a student acquires in solving ill-structured design problems, and its influence on the quality of design are investigated. The approach in the studies described in this chapter is to look in detail at the problem-solving processes of novice design students.

The theoretical background of knowledge acquisition and learning is primarily based on studies into the process of solving well-structured problems, such as problems in physics and mathematics. Solving ill-structured problems in domains akin to design engineering are less frequently explored objects of research (see e.g. Eckersley, 1988). A possible explanation for this paucity is the difficulty encountered in analysing solution processes for these kinds of problems, with their typically heuristic nature. Since it is difficult to give precise and explicit descriptions of complex solution processes, rules and methods for educational practice are mainly based on non-validated models of the design process. What education today needs, through individual or group exercises, is knowledge which can be taught explicitly, as opposed to the often very implicit fashion in which knowledge about complex solution processes must be mastered.
In search for relevant knowledge in the area of solving ill-structured problems it seems appropriate to begin with what is already known about solving well-structured problems.

3.2 *The domain*

Acquiring design knowledge and skills is, for several reasons, a very complex activity. Firstly, in order to design a product students need to understand concepts and procedures from several domains. When taught in isolation this knowledge could be compartmentalised instead of integrated as in the design activity. Secondly, the design activity itself is usually thought to be a valuable teaching tool - 'learning by doing' - in that the students experience not only the problem and the information needed but also the problem solving strategy. However, because of the complexity of design problems and the heuristic character of the process involved in solving ill-structured problems, it is almost impossible to give students clear and detailed working methods, like algorithms, to consistently attain a good design result. Descriptions of these methods in the domain of industrial design, for example from Archer (1965) and Jones (1970), are all equally superficial in that it is hard to deduce from them rules which could guide design activities. This is equally true for the attempts to describe design processes in detail (e.g. Ullman et al., 1988). For this reason they are not very useful regarding instruction either. Hence, within design education, any information about types of knowledge and sorts of skills to be mastered in an attempt to improve the design activity are mainly available on an intuitive level.

Only recently attention has been paid to the question of how the understanding of knowledge in design can add to design theory and education. Research on this topic has been conducted mainly in well-structured problem domains, such as physics and mathematics (e.g., Larkin et al., 1980; Chi, Feltovitch, & Glaser, 1981; De Jong & Ferguson-Hessler, 1986; Cooper & Sweller, 1987; Sweller, 1989). These and many other studies show that detailed domain-specific knowledge is necessary to successfully solve problems. Central is also the idea that a suitable, organized cognitive structure plays a crucial role in the quality of the problem solving process, especially in encoding and retrieving knowledge that is relevant to the problem at hand. For instance, according to schema-theory, this structure is composed of problem schemata or problem types, which enable the problem solver to categorize the problem, to identify what knowledge should be used and to plan the right actions (e.g., Rumelhart, 1980). The process of learning can thus be described in terms of schema acquisition and rule automation, defined by Anderson (1983) as knowledge *compilation*. Research indicates that experienced problem-solvers have an extensive knowledge of problem types and tend to sort problems by solution procedure (Mayer, 1987).
These and other theoretical ideas about prepackaged information stored in memory, like *scripts* (Shank & Abelson, 1977) and *chunking* (Larkin, 1979), are not common concepts within the domain of design and design engineering, although different authors recognize the importance of them (e.g. Akin, 1986). The common sense idea in designing is that a mysterious metacognitive force plays an important role in the solution finding of design problems. As Akin (1986) states:

> "Even in more recent studies, design and creativity are occasionally attributed to mystical forces sealed in this black box and claimed not to be fit for study." (Akin, 1986, p. 3)

This suggestion can be found in several anecdotal and (auto)biographical reports on important discoveries, which are based mostly on retrospections, hence they are not valid sources (Weisberg, 1986). However if taking a closer look, the boundary between these and well-structured problems is rather vague and fluid (Simon, 1973). On account of the need for knowledge from different domains and because of the heuristic character of the process, it is believed that solving ill-structured problems relies additionally on general process knowledge: knowledge of managing and monitoring the solution finding process without regard to the domain. Knowledge of more general methods and heuristics of this kind are denoted *weak methods* by other authors (Anderson, 1987; Langley et al., 1987). Even if one agrees that the processes involved in solving ill-structured problems are not qualitatively distinct from processes found in solving well-structured problems (Greeno, 1980; Weisberg, 1986; Langley et al., 1987), it is still necessary to have knowledge on how this should be done and on how to integrate content knowledge from different domains. The assumption is that knowledge of this kind can be taken as a distinct component along with knowledge of the domain. In improving education within design engineering attention then should be paid both to domain-specific knowledge of all important and relevant domains, e.g. mechanics and ergonomics, and to domain-independent general process knowledge necessary in the management or control of the problem-solving process: the student needs to reflect on what

he/she is doing in solving a design problem, to understand the process and strategies underlying the most efficient way to reach a solution. Both knowledge components are important in education, although the balance of importance is often discussed (see for an interesting overview of this debate Bransford et al. (1986) and Alexander & Judy (1988). Since Gagné (1965) states that the outcome of the learning process is the acquisition of higher-order rules which are capable of being generalized in a wide variety of stimulus situations, an increase of process knowledge during the learning process can be expected.

To state the problem more specifically, the *first aim* of the studies here, presented in this and the following chapter is *to understand what knowledge is encoded, retrieved and applied by a student during the design process, how he or she manages the problem-solving process and to what extent it affects the resultant design. In other words, how does the knowledge base of the (novice) designer affect the quality of the design?*
In design education this question should be seen as paramount: in order to teach relevant knowledge one has to know precisely what knowledge is necessary for problem-solving.
The *second aim* of our research has an instrumental nature: *what methods and techniques of elicitating knowledge from subjects with a different level of expertise are useful in relation to the domain of design engineering?*
In the studies described in this chapter the knowledge elicited by novice designers by way of writing retrospective learner reports is investigated. Firstly, the knowledge concept will be explained and defined. Next, the elicitation technique used will be considered in terms of instrumental value.

3.3 *Knowledge categories*

An understanding of the designers knowledge base, which is used in solving design problems requires a more detailed description of the relevant knowledge. However, research on cognition and learning has proliferated numerous terms, which are generally very loosely defined or confused by overlap (cf. Alexander et al., 1991).
Firstly, a generally accepted classification of knowledge is made between *domain-specific knowledge* and domain-independent *general process knowledge*. In design, domain-specific knowledge refers to academic knowledge of basic disciplines together with knowledge of designing. The hypothesized relationship between knowledge components and the design activity is presented in figure 3.1.

In a study on student learning in architectural design Venselaar et al. (1987) distinguish two content-related *knowledge components* within the domain-specific knowledge, together with domain-independent knowledge:

1 Domain-specific *basic knowledge* in design refers to academic knowledge of different disciplines like mechanics, ergonomics, marketing, etc. Initially, no discipline is excluded.
2 Domain-specific *design knowledge* refers to knowledge of the design discipline itself, which is related to solving the design problem at hand and to the integration of domain-specific

basic knowledge and general process knowledge; for example, knowledge of the possibilities of specific materials to attain certain concept solutions, knowledge of (the application of) design methods, knowledge of existing design solutions, etc. Together with basic knowledge, design knowledge is specific to the domain of industrial design.

3 General *process knowledge* refers to domain-independent knowledge, a more general kind of expertise. Often this kind of knowlege comes into play when heuristics, or 'weak methods' are needed. General process knowledge can also be regarded, in the main, as the monitoring function of memory that helps the student to organize the problem-solving process as a whole. It refers to a reflection on the design process by way of knowing what stages are relevant in the problem-solving process and what methods can be used to facilitate it.

Thus, it is assumed that basic and design knowledge are both domain-specific, as is illustrated in figure 3.1.

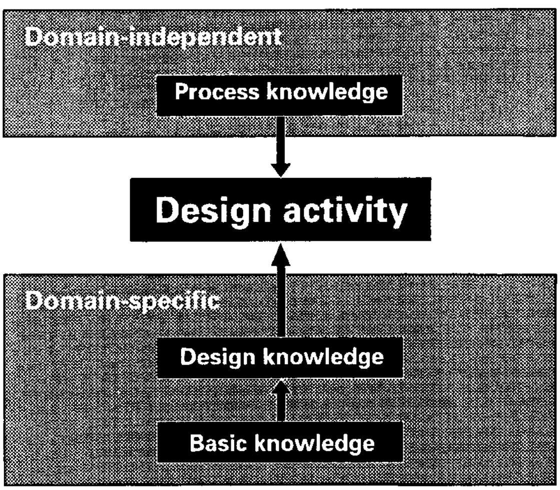

Figure 3.1 Knowledge and design activity

If the aim is to understand what and how knowledge is applied, or has to be applied, in order to find the optimum design solution, this rough classification needs elaboration.

In describing and analysing knowledge types the analytical physics problem solving classification of Ferguson-Hessler & De Jong (1990) is adopted here as a starting-point. The classification is based on widely accepted theoretical notions. They describe the knowledge base in terms of four major types (see also Alexander & Judy, 1988; and Alexander et al., 1991):

1 *Declarative knowledge* refers to factual information within a certain domain (knowing what). The term is derived from Anderson (1983) who also assumes a declarative memory, according to his theory of adaptive control of thought (ACT).

2 *Procedural knowledge*: how to use declarative knowledge in certain processes and routines. This knowledge contains actions and manipulations that are valid within a domain. The term is again derived from Anderson's ACT theory.
3 *Situational knowledge*, also called *conditional* knowledge, entails the understanding of when and where to access certain facts or employ particular procedures.

The classification of these three types of knowledge is endorsed by different theorists. As Alexander et al. (1991) state:

> "Whether we are speaking of content knowledge, linguistic knowledge, or any other form of knowledge, we hold to the premise that any of these forms can contain declarative, procedural, or conditional knowledge."(Alexander et al., 1991, p. 323)

They emphasize this distinction between the three knowledge types in connection with knowledge acquisition. Acquiring knowledge in one form does not automatically guarantee knowledge in the other forms.
Ferguson-Hessler & de Jong (1990) add a fourth type of knowledge:

4 *Strategic knowledge* refers to knowledge of processes that are effortful, systematic, and consciously invoked to facilitate the acquisition and utilization of knowledge. The term strategic also refers to the algorithms and heuristics that are involved in planning the sequence of actions from problem to solution.

Table 3.1 Classification of knowledge (From Venselaar et al., 1987)

	Domain-specific knowledge		General
	Basic knowledge	Design knowledge	Process knowledge
Declarative knowledge	Knowledge of facts and formulas 1.1	Knowledge of design facts and methods 1.2	Knowledge of methods to optimize the process 1.3
Procedural knowledge	How to use these facts and formulas 2.1	How to use these design facts/methods 2.2	How to use general optimization methods 2.3
Situational Knowledge	When and where to use this basic knowledge 3.1	When and where to use this design knowledge 3.2	When and where to use this process knowledge 3.3
Strategic Knowledge	Knowledge of algo-rithms and heuristics of relevant domains 4.1	Knowledge of heuristics in solving design problems 4.2	Knowledge of algorithms and heuristics in problem solving 4.3

This classification of knowledge types seems useful especially in analysing routine problems as are often met in studies on solving physics or maths problems; problems which are well-structured.
Applied to the above classification for the two components, i.e. domain-specific knowledge and general process knowledge, an assumption within both components that the four knowledge types (declarative, procedural, situational, and strategic) are distinct is made. The result is a classification of twelve categories postulating the knowledge-base of the designer (see table 3.1).

For example, strategic knowledge can be recognised within strategies on a domain-specific level and on a general process-level. Support for this distinction is found in literature where two kinds of strategies are described, goal-limited and general strategies (Alexander & Judy, 1988). Goal-limited strategies are more or less specific for a particular domain, although there is the possibility of some kind of generalization. General strategies are broadly applicable, often considered as valid across domains, sometimes labeled as: metacognitive knowledge. From this the possibility arises to look at strategies as a continuum, with, at one end, goal-limited strategies (beginning with task-limited strategies, only valid for one specific problem) and at the other, general strategies, i.e. the possibility to monitor and plan an entire ill-defined problem solving process.
Later in this chapter examples of the encoded knowledge are presented to explain the distinction between different knowledge classes (see box 3.1 and 3.2, and appendix III).
Although Venselaar et al. (1987) used the matrix in a study on the architectural domain, they did not really validate the method. Thus, the utility and reliability of the classification as an instrument for encoding and analysing knowledge applied by designers during the design process must be determined and evaluated. The assumptions underlying the classification are still hypothetical.
Therefore, a supplementary aim of this study will be to investigate the methodological implications of knowledge measurement, and the practical applicability of the classification used. The distinction within domain-specific knowledge between basic and design knowledge seems relevant, since it contributes to the insight of the content knowledge used in design. On the other hand the distinction between process knowledge and strategic knowledge is less clear if compared to literature definitions. However the separate knowledge classes are difficult to define.

3.4 *Elicitation techniques*

3.4.1 *Retrospective data*

Investigating the thinking process of a problem solver means that information processing and knowledge activation must be physically recorded. What technique could be best employed to elicit the relevant information concerning a designers information processing activity during

the design process? Knowledge implicated within expert performance is not directly observable. Hence, the problem becomes how to encourage designers to express verbally and visually exactly what they do.

There are different elicitation techniques involved in the development of expert systems, some of which are known from psychological research and some from knowledge engineering. The most common techniques are concurrent verbal reports from the problem solver, by way of 'thinking aloud', and retrospective self-reports. The concurrent thinking aloud report seems to be the closest reflection of the actual cognitive processes involved (Ericsson and Simon, 1980). For this study, concerned with cognitive processes involved in designing, this method seems most appropriate. In chapter 4 a study is described in which design students are observed whilst solving a design problem and meanwhile thinking aloud. The use of this technique and its associated problems will be discussed fully there. However, this technique of thinking aloud during problem solving is difficult to realize within an on-going educational program of design projects; the practicability could be hampered by all sorts of problems, and moreover the technique may disturb the ongoing education process.
The primary aim here was to study the design process within a standard design curriculum. Therefore, although it refers to a cognitive process that is completed and cannot be altered or influenced, a technique based on retrospective reports seems also appropriate (Ericsson & Simon, 1980).

The opportunity was available to make use of already existing retrospective reports of first-year students in the School of Industrial Design Engineering. As part of the design course students are asked to write a 'learner report' at the end of or midway through a design project. This method, introduced by De Groot (1974), implies that the problem solver writes his or her learning experiences over the preceding period, starting each experience with: "I have learned (that or how)...". De Groot developed a theory towards the assessment of educational learning objectives. Central to this theory is the problem of content validity, i.e. the question of whether the learning effects, as measured in school, adequately reflect the intended goals of the programme. De Groot argues that the problem can be solved by obtaining learner reports from students (in Van der Kamp, 1980).

> "Learning results in programmes stored in memory. These are programmes the student can use and steer himself freely and consciously". (De Groot, 1975)

Van Eyk (1982) introduced the method of writing learner reports as a teaching tool at the School of Industrial Design Engineering at Delft University. He expected that design students writing learner reports at regular intervals throughout their projects would consequently allow staff to interact more effectively and satisfactorily. The learning effects and the actions, mentioned in the reports, formed the basis for the intended dialogue between staff and student (Van Eyk, 1982).
In order to transcribe and encode the retrospective data De Groot (1974) introduced a classification system of learning effect sentences according to two dichotomies: (1) students

may (report to) have learnt either general or particular operating rules (exceptions to preconceptions), and (2) they may have learnt something about the world, or about themselves.
Based on these theoretical notions Van der Kamp (1980) made use of learner reports from students in secondary education in order to gain more insight into the objectives and learning effects of teaching art subjects. He also encoded the reports according to the classification system of De Groot.
However, in analysing the learner reports in terms of knowledge types and components, this classification with four types of learning effects seems too approximate. It is assumed that only by a systematic way of encoding the data, instead of a rough inspection of it, reliable and accurate statements can be made. The question is whether students' experiences *in retrospect* lend themselves to statements about knowledge acquisition, according to the classification of the knowledge matrix in table 3.1.
To answer this question the validity of both the knowledge classification as an analytical tool and the retrospective reports as utterances of the thinking process are at issue. Although the aforementioned classification system (table 3.1) is employed in the study of Venselaar et al. (1986), the validity of the system was not investigated; therefore, the validity will be tested here empirically. With regard to the validity of verbal reports more data are known from literature, which is discussed throughout the next paragraphs.

3.4.2 **Disadvantages of retrospective reports**

As a number of studies show, retrospective reports can elicit different knowledge categories, although of course not all the knowledge acquired or applied by the problem solver is reported. Techniques using retrospective data are considered less valid than 'expertise-in-action' techniques, because they do not reflect the actual processes in problem solving. Unless the subject reports immediately after task completion, while information is still retained in short-term memory, the information must be retrieved from long-term memory. In retrieving experiences subjects have access to an extremely large base of relevant knowledge. The time lapse will behave like a sieve; unsure which events or knowledge will be retrieved and whether these events are representative (Ericsson & Simon, 1984). Perhaps merely the most outstanding events will be remembered, while processes which are fully automated (proceduralized), through practise during the design course, are verbally unobtainable (Anderson, 1983). Even then, only the superficial aspects will be memorized before the small details.
Hence, an important condition for eliciting valid reports is that the report is made immediately after finishing the problem solving task. In the literature regarding the validity of reports, studies are mostly discussed concerning the task which is performed within a laboratory setting, where the subject has only limited time. However, with regard to learner reports in the setting of design education, some design tasks take six weeks, after which students write up their learning experiences. What can be expected from the memory of students?

Another issue in evaluating retrospective reports is the way in which subjects are prompted to tell or write their experiences. Learner reports by students in our sample were initiated by the prompt: "I have learned ...". How is this prompt interpreted by students? The assumption is made that it elicits information mainly on the general characteristics of the thought process because explicit questions on its details are lacking.
According to De Groot's idea (1975), students report about programmes stored in memory. If this is so, we may attach value to these verbal experiences. Moreover, the results of the learner report can be useful as a relative measure when comparing different (groups of) problem solvers or different stages in the design process. Through this comparison the amount of domain knowledge and the quality of this knowledge - in terms of the aforementioned knowledge categories - can be measured. Both seem worth analysing, since they play an important role in solving well-structured problems (De Jong & Ferguson-Hessler, 1986).

3.5 *A criterion measure*

In most investigations on problem-solving a causal relationship is hypothesized between a students prior knowledge or expertise and the way, using certain knowledge or strategies, he or she solves the problem. In the studies presented in this chapter there were several reasons to focus on the relationship between the knowledge acquired throughout the first-year design courses and the quality of the design work produced. Knowledge acquired was defined by the knowledge elicited in learner reports, while product creativity, as defined in chapter 2, was the criterion with regard to performance quality. Although the arguments regarding this choice will be explained fully in the next section, they are outlined below. Firstly, in this study the primary interest was to investigate designing as an educational process. Observing first-year students from the start of the design course throughout the year would give the opportunity to study the development in knowledge acquisition of novice designers. In order to differentiate between good and poor performers subjects should be selected either on differences in entrance selection or in achievement level for the relevant subjects within secondary education. However in the Netherlands, universities don't have entrance selection; moreover, design-related subjects in secondary education do not really exist. Secondly, there was a practical reason for avoiding any differentiation beforehand. A year after finishing the first creativity study it was decided to use the learner reports of the same group of students as an information carrier with respect to knowledge acquisition. From the 44 students whose product creativity was measured only 20 could deliver a nearly complete record of 4 learner reports, written during that year. All 20 records were included in the analysis. Thirdly, because the analysis was done two years after the students had finished their first year, it was of course possible to take the marks of the design teachers as a criterion for good and poor performance. However, as stated in chapter 2, marks given by design teachers are not a very useful criterion because each mark is based on the subjective judgment of only one teacher, which leads to unreliable assessment. Design teachers give an over-all judgement, combining different criteria, ranging from product to presentation aspects. A less subjective judgement

was preferred. The product creativity rating (PCR) as measured by the consensual assessment technique (see chapter 2) gives a more reliable criterion. But this rating was only determined *after* the students had finished their first-year design course.

3.6 *Study I*

3.6.1 *Method*

Subjects

Within the scope of the creativity research, data were gathered from the 1985 freshmen population of the School of Industrial Design Engineering (IDE). A random sample of 60 (out of 200) first-year students was drawn. The common schooling background of students in the Netherlands is the 'VWO', which is the secondary education system preparing the student for university.[3] A small group of first year student backgrounds (about 15%) deviated from this norm. Some of these students held degrees in higher vocational education, some enroled after a year within another discipline at the same university, and others came from abroad. Their experience in designing was unknown. In order to draw reliable conclusions from our data, we prefered to select only the VWO-students because of their homogeneous background. After this selection the sample consisted of 44 out of 60 students. This sample was involved in the creativity assessment, as is described in chapter 2.
One year after this assessment study an effort undertaken to trace the learner reports of these same students. During their first year they wrote 6 reports (see next paragraph). Students from the sample were asked by letter to send their reports. Furthermore, part of their records were obtained from the files, saved by the project-staff. A complete student record with all six learner reports was obtained for 17 students in the sample. Another 3 records were added with only 1 report missing. When a report was missing the sum scores of codes for that report were estimated, based on the average sum scores for the other reports of the same subject. This procedure was executed after all reports had been encoded.

Design course

The design course is part of the first-year program, taking 168 hours of the total amount of 1800 hours in the first year. The curriculum is organized in four periods ('quarters') of ten weeks. Each quarter consists of a 7-week period of lectures, and a 3-week period of examinations. In 1985-1986 four design projects, of different length, formed part of the first-year design course; this course ran during the period of lectures. Project I took one shift (=4 hours) a week during two weeks, 8 working hours in total. The task was to design a waste basket for a specific situation. Students worked in groups of 4-6 students, the common group size for design projects in the first year (the composition of groups was different for different

[3] In the Dutch education system universities are not allowed to apply entrance selection by either tests or interview; i.e. all students who pass the final examinations of secondary education (VWO) have the right for university entrance. For entering universities of technology 'Mathematics' and 'Physics'must be included as part of these final examinations, while 'design' is not incorporated within the VWO-program at all. Hence, first-year students are a homogeneous group in that they lack design experience.

projects). Project II took one shift a week during four weeks (16 hours). The task was to solve the problem of heating food in the open air (a form of barbecue). Again, students were working in groups. As can be seen in table 3.2 both projects I and II took place during the first quarter. Project III took two shifts a week during six weeks of the second quarter (48 hours). Half of the students got the brief to design a 'public telephone booth', and the others a 'computer cabinet'. The information collection together with the draft of a list of requirements, was performed in groups. From the conceptual phase students worked individually. Finally, project IV covered the third and fourth quarter, two shifts a week during 6 weeks of each quarter (96 hours). The project was thus interrupted by an examination period. As for the first two projects students were working in groups. The general problem in the fourth project was concerned with the design of play-equipment for 4-8 years-old children, but for the various groups the brief was altered so as to evoke different design solutions.

Learner reports

As part of the design project the student had to write his or her learning experiences at the end of each project. The instructions were:

- Learning experiences must be written in type-script, the 'house-style' of the School, on A4 format.
- For each project or project part the maximum size of the report is one page.
- The page should be subdivided into three sections:
  * An introduction into the content of the design project.
  * Learning experiences regarding the project just completed. The following standard sentences may be helpful: "I have learned that... (or) how to... (or) that it is not always true that..."
  * A beginning for consequent actions related to one or more of the learning experiences, e.g. "Next time I will (not)...".

At the end of all four projects students wrote learner reports. Because of the length of the fourth project an intermediate learner report was written halfway through the project.

In table 3.2 a summary is presented of the data mentioned previously: a time schedule of each design project, the number of sessions per week, whether designing is conducted in groups or individually, and the moment of writing learner reports. The double lines at the end of each quarter point to a three week period of examinations, during which time no design projects ran.

Transcription of learner reports

Each learner report consists of three paragraphs: (1) an introduction to the design problem, (2) the learning experiences absorbed, and (3) the consequent actions, based on what has been learnt. Only the learning experiences were used in our knowledge analysis. In the actions

paragraph these experiences were often repeated. Moreover, actions could not always be conceived to be learning experiences. Segmenting the reports was done individually by each encoder. This was rather easy, because during the training sessions the encoders agreed upon starting a new line of encoding with a full stop after each sentence (see also encoding procedure).
All learner reports, without the names of the students, were copied and provided to each encoder.

Table 3.2 Some characteristics of design projects during the first year

	1st Quarter		2nd Quarter	3rd Quarter	4th Quarter
Project	I	II	III	IV	
Weeks	2	4	6	6	6
Sessions/week	1	1	2	2	2
Group/Individ.	g	g	i	g	g
Learner report	end	end	end	halfway	end
Hours in total	8	16	48	48	48

Encoding procedure

Encoding of learner reports was accomplished by four encoders. First, as an expert in the theoretical aspects of the aforementioned knowledge-matrix the author of this matrix was engaged. He also administered the training sessions. The second encoder was the author of this book. Both are psychologists. Next, because of their involvement in the first-year design course, and their consequent expertise regarding the knowledge acquisition of these particular students, two design teachers, with a professional designers background, were asked to participate.
The research project started with a number of joint training sessions. In the first the knowledge categories of the matrix were explained. Examples of knowledge statements from each of the 12 categories were presented and discussed. Next, the encoders practised individually with learner reports from students outside the sample. The codes were then sent to the author who compared them, and sent them back with his comments. In the second session the data, together with the comments, were discussed. The same procedure - practice, feedback, and discussion - was repeated six times over a period of three months. During this time the author tried to derive consistent, congruent rules for encoding. These rules were recorded together with the comparison of the codes, and, after discussion, accepted in the same or in a modified version. However even after this training period the encoding of learner reports using the 12 knowledge categories appeared to be difficult; although towards the end there was improved inter-encoder agreement, however the percentage of disagreement was still more than 30%.

All data and conclusions were recorded in a progress report. From this report encoding rules for every row and column of the matrix were derived. In the boxes 3.1 and 3.2 these rules are presented.
The four rows consist of: declarative, procedural, conditional and strategic knowledge; the three columns are basic, design, and general process knowledge.

Basic knowledge
Knowledge and skills that are supplied by other domains e.g. * knowledge of mechanics, ergonomics, materials * Drawing skills * Social skills and knowledge of group dynamics (cooperation, leadership) Experiences suggesting 'learning about yourself' Knowledge about the working conditions (use of the studio and the workshop, etc.)
Design knowledge
Knowledge and skills that are involved in the current design task Keywords (in the reports): Designing, product design, prototype, model When basic knowledge is integrated to solve the current design problem (and as such mentioned by the student) In case of doubt between design knowledge and process knowledge: keywords for design knowledge: a certain design or design situation that is related to the current design problem
General process knowledge
Knowledge that is abstracted from the current design task, defined as: *metacognitive* knowledge (evaluation and control) * Awareness of the importance of process stages or a certain sequence in process stages * Evaluation of personal activities Knowledge that is related to the process or episodes in the process Knowledge of techniques for optimizing the process e.g. * techniques for idea generation The need for making explicit ideas, decisions or results; e.g. "a good presentation of my ideas is important" A statement is coded as 'process knowledge' when a subject shows understanding of the meaning of the design process or techniques optimizing the process at a higher level than that of the current design project; e.g. "Without adequate background-information it is impossible to make a problem definition and a good and complete program of requirements."

Box 3.1 Encoding rules regarding the three columns of the knowledge matrix: Basic knowledge, design knowledge and general process knowledge

Declarative knowledge
Keyword: ("I learnt) *that...*" Value statements like: "I learnt that x is important(useful, nice, difficult etc.)" Example: "I learnt that designing is difficult"
Procedural knowledge
Keyword: ("I learnt) *how...*" or sometimes: ("I learnt) *to...*" When insight or understanding of the procedure is evident
Situational knowledge
Keyword: ("I learnt) *when...*" or *if..then*" This knowledge type asks not only for the keyword, but also for an action The application of rules in specific situations
Strategic knowledge
Keywords: "*Before I...*" or "*First, I* start with.." When a sequence of activities is planned in time When algorithms (*strong methods*) or heuristics are reported (*weak methods*) The concept 'planning', used in learner reports, often points to a certain technique, which students must learn. Phrases like: "To elaborate on my planning is difficult" or "I haven't finished my planning yet" are conceived as basic, declarative knowlede

Box 3.2 Encoding rules regarding the four rows of the knowledge matrix: Declarative, procedural, situational and strategic knowledge

Moreover, some general encoding rules were formulated:

1 In analysing a learner report, omit the introduction and activity sections, only transcribe the second part, i.e. the learning experiences of the report.
2 Give a number to every sentence. A sentence is finished after a semi-colon or a full stop.
3 Divide the sentences into segments. A segment is defined as one knowledge statement. Often a segment coincides with a sentence; if more than one sentence belongs to a knowledge statement, put them together; for example (1) the second sentence is an explanation of the previous learning experience, (2) the next sentence can only be understood by the the previous sentence, and (3) a number of sentences together suggest strategic knowledge with keywords like *first.., next.., and finally...*
4 Start with assigning a code to a segment concerning one of the *columns* of the matrix; thus determining whether it is basic knowledge, design knowledge or process knowledge.
5 Assign next a code to each segment concerning the *rows* of the matrix: declarative, procedural, situational, or strategic knowledge. If necessary, reformulate sentences so that

one of the keywords - *that..*, *how..* or *when..* - can be used. But avoid any personal interpretation.

6 When, for reasons of deviant content, a segment cannot be encoded according to the 12 categories, give it a '0' code.

7 Don't dig too deeply. Stick to simple rules.

After the training sessions the encoding of the subject reports in the sample began. Each encoder was asked to transcribe, segment, and encode one subjects set of learner reports completed during the year. The reports were offered as typewritten documents without the name of the student.
The encoders were unrestricted as regards where they undertook this task, as long as they worked individually. They assigned one code from the columns of the matrix (basic, design or process knowledge), and one from the rows (declarative, procedural, situational or strategic) to each learning experience. Hence, one of the 12 categories from the knowledge matrix (see table 3.1) were chosen. When ready they returned it to the author, and received the next report. Deadlines were identical for each encoder. In this fashion the reports of all 20 subjects were encoded. The author processed the data by counting the codes per knowledge category, separate for every design project after which the learner report was written. In order to determine the inter-encoder agreement the data of the four encoders were compared. If one encoder gave a code to a certain sentence in a report, while the other encoder did not, the code was removed only when comparing these two encoders.
Each of the encoders judged over 700 experiences.

Examples of learning experiences are mentioned in Appendix III. For a short impression, in box 3.3 is presented an overview of learning experiences, one experience in each of the 12 categories, as coded by all four encoders, The column 'cat.' refers to one of the 12 categories in the matrix. The codes of the categories are mentioned in table 3.1.

Creativity measurement

Because project III in the design course was performed mainly individually, the products designed in this project were chosen for creativity assessment. In chapter 2 the way creativity is measured is described in detail.
The group of 20 subjects, whose learner reports are analysed here, were part of the sample of 44 students in creativity study I. In order to give each design a score for creativity a 'Product Creativity Rating' (PCR) was used, i.e. by averaging the creativity scores of the 10 design teachers involved in the study a final mark could be reached. For each of the 20 students in the sample a PCR was available.

"I have learnt..."	Cat.
...about wood linking and construction.	1.1
...that in this design task much attention must be paid to constraints and specifications.	1.2
...that the design process is made up of an alternation between creative and exact stages.	1.3
...how to handle machines and manufacturing methods.	2.1
...how to pose a design problem, to make a list of requirements, to describe the users and to write a chronological design report.	2.2
...that if the function of the object is ambiguously stated, then you have to define the problem clearly yourself and emphasize specific operation by drawing the concepts.	2.3
...if the paint is going to flake, then use paint which adheres better.	3.1
...that the use of colours can clarify chaotic situations and that colours can give meaning to your design.	3.2
...if you get stuck within the idea-generation, try to start from totally different points of view in order to create new ideas.	3.3
...that I have to keep up my report by making notes throughout the process. Otherwise I forget the details.	4.1
...before making the scale model I have to check if the required materials are available (in stock).	4.2
...that gathering information and determining the requirements before generating ideas is very efficient.	4.3

Box 3.3 Examples of learning experiences, one for each category (see also Appendix III)

3.6.2 *Results*

Inter-encoder agreement

The first analysis of the reports is concerned with the inter-encoder reliability, the agreement between the four encoders of learner reports. One of the measures to estimate inter-encoder agreement between pairs of judges is Cohen's coefficient *Kappa* (κ).

This measure, for a CxC table is corrected for chance as is shown in the formula (Cohen, 1960):

$$\kappa=\frac{p_o-p_c}{1-p_c}$$, in which

$$p_o=\frac{1}{n}\sum_{i=1}^{c} n_{ii}$$, the proportion of units on which the judges agreed,

$$p_c=\frac{1}{n^2}\sum_{i=1}^{c} n_{i+}n_{+i}$$, the proportion of units for which agreement is expected by chance.

Values of κ can range from $-p_c/(1-p_c)$ to 1. If $p_o=p_c, \kappa=0$

As table 3.3 shows, the differences in agreement between pairs of encoders are obvious. In calculating the coefficient also the '0' codes, assigned when the codes of the matrix did not apply, were included.

Table 3.3 Agreement between encoders, using average Kappa-coefficients

Encoders	1	2	3	4
1. Psychologist 1	-			
2. Psychologist 2	.43	-		
3. Design teacher 1	.26	.28	-	
4. Design teacher 2	.22	.25	.20	-

In general the inter-encoder agreement seems rather low, although the coefficient for the two psychologist encoders is better. Apparently, differences between the judges depend partly on idiosyncratic tendencies in the encoding activity, defined by the professional background of the judge. But what can be said about the validity of the classiffication instrument used, or about the usefulness of the verbal reports as data? In order to evaluate the results a further analysis is needed.

In table 3.4 the scores of psychologist (1) and design teacher (3) are compared on all codes in the 'knowledge matrix' of all 12 categories. The codes reveal the sum totals of all subjects for all five learner reports. The '0' codes are not included.
A number of conclusions can be drawn.

- The proportion of agreement (values on the diagonal) is 30%.
- The marginal totals differ significantly between the two judges (χ^2=396.2; df=9). For instance, learning experiences, encoded by judge 1 as category 1.1, are classified by judge 3 in nearly all 12 categories.
- The proportion of codes in the *declarative* knowledge categories (1.1, 1.2, and 1.3) is 77% for judge 1 and 67% for judge 3.

Table 3.4 Agreement in knowledge categories between judge 1(psychologist) and 3(design teacher)

1985	Judge 1												
Judge 3	1.1	2.1	3.1	4.1	1.2	2.2	3.2	4.2	1.3	2.3	3.3	4.3	TOT
1.1	69	8	-	-	7	1	-	-	5	2	-	1	93
2.1	4	-	-	-	-	-	-	-	-	-	-	-	4
3.1	4	2	1	1	1	-	-	-	1	-	-	-	10
4.1	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2	30	7	1	-	54	6	-	5	26	10	1	2	142
2.2	9	4	-	1	11	2	-	-	4	4	-	-	35
3.2	14	4	2	1	21	4	-	-	9	6	1	2	64
4.2	1	-	-	-	1	-	-	4	1	1	-	-	8
1.3	73	5	-	1	42	7	1	2	63	14	-	11	219
2.3	13	1	1	-	10	5	-	-	15	7	-	1	53
3.3	11	3	1	2	6	1	-	-	6	1	2	2	35
4.3	3	-	-	-	2	-	-	1	2	-	-	3	11
TOT	231	34	6	6	155	26	1	12	132	45	4	22	674

A second comparison in the same way is done for the two psychologist judges, as is shown in table 3.5. Analysis of this matrix gives a slightly different picture.

- The proportion of agreement (values on the diagonal) is 52%.
- The marginal totals are in closer agreement between the two judges, but still differ significantly (χ^2=54.1; df=11).
- The proportion of codes in the *declarative* knowledge categories (1.1, 1.2, and 1.3) is 77% for both judges.

The scores of judge 1 differ between table 3.4 and 3.5. As is mentioned previously, this is caused by the fact that, when one encoder gave a code to a certain sentence in a report, while the other encoder did not, the code was removed when comparing these two encoders.

To summarise, the proportion of agreement between the psychologists on the one hand and the design teachers on the other is so small, that using only the agreed codes of all four encoders in order to analyse the 'knowledge base' of the subjects cannot be justified. Therefore, it was decided to select only the codes of the psychologist judges for further analysis. However, once the non-agreed codes had been removed, only about 50% remained, although it did prove possible to combine different categories in order to raise this proportion.

Most plausible were two combinations, the first one was to combine the knowledge components (basic, design, and process knowledge), and to analyse the four knowledge types (*declarative, procedural, situational and strategic*), the second one was the complete opposite, combining the four rows of the matrix and to analyse the three knowledge components (*basic, design and process*).

Table 3.5 Agreement in knowledge categories between the 2 psychologists, judge 1 and 2

1985	Judge 1												
Judge 2	1.1	2.1	3.1	4.1	1.2	2.2	3.2	4.2	1.3	2.3	3.3	4.3	TOT
1.1	182	8	-	1	29	4	-	4	17	5	-	4	254
2.1	4	17	1	-	1	-	-	-	1	-	-	-	24
3.1	3	1	1	1	1	-	-	1	1	2	-	-	11
4.1	6	1	-	3	2	-	-	-	7	1	-	-	20
1.2	41	4	5	-	61	4	-	1	12	6	-	-	134
2.2	1	1	-	-	3	7	-	1	1	2	-	-	16
3.2	1	-	-	-	6	1	-	1	-	-	-	-	9
4.2	2	-	-	-	1	1	-	8	-	-	-	-	12
1.3	21	2	-	2	47	5	1	-	75	16	-	3	172
2.3	-	1	-	-	6	6	-	-	13	15	1	4	46
3.3	2	-	-	-	5	-	-	-	-	-	3	2	12
4.3	1	-	-	-	1	-	-	-	6	1	-	11	20
TOT	264	35	7	7	163	28	1	16	133	48	4	24	730

In order to perform the analysis on each combination the row codes and column codes from table 3.5 are added separately. In tables 3.6a to 3.6d the agreement between judges 1 and 2 within each row is presented, as is done for each column in tables 3.7a to 3.7c.

Agreement between judge 1 and 2 for each row of the knowledge matrix

In the method used here to analyse the agreement of the two psychologist judges within each knowledge type (rows in the knowledge matrix) all codes of both judges are taken into account which belong to the same row. For instance, codes of both judges, for the same learning experiences, within the row of declarative knowledge (categories 1.1, 1.2 or 1.3) are

compared. The results for each row are presented alongside. By this approach a proportion of 77% from the original table 3.5 is analysed (560 out of 730).

Table 3.6a Declarative knowledge

Declar. knowl.	1.1	1.2	1.3	TOT
1.1	182	29	17	228
1.2	41	61	12	114
1.3	21	47	75	143
TOT	244	137	104	485

Table 3.6b Procedural knowledge

Proced. knowl.	2.1	2.2	2.3	TOT
2.1	17	0	0	17
2.2	1	7	2	10
2.3	1	6	15	22
TOT	19	13	17	49

Table 3.6c Situational knowledge

Situat. knowl.	3.1	3.2	3.3	TOT
3.1	1	0	0	1
3.2	0	0	0	0
3.3	0	0	3	3
TOT	1	0	3	4

Table 3.6d Strategic knowledge

Strateg. knowl.	4.1	4.2	4.3	TOT
4.1	3	0	0	3
4.2	0	8	0	8
4.3	0	0	11	11
TOT	3	8	11	22

In general most coded learning experiences - 87% - are within the group of declarative knowledge. Within this declarative row, 65% of the codes are in agreement, while the distribution of the other codes show confusion between all three colums (κ=.46).
Within the procedural row the confusion concerns mainly the choice between design knowledge and process knowledge (κ=.69).
Situational and strategic knowledge are hardly mentioned (κ=1.00). Both types of knowledge seem difficult to verbalize, probably because they are no longer in conscious memory. Also the amount of procedural knowledge is relatively small.
The consequence of what is found here being that a further analysis based on the rows of the matrix would be futile.

Agreement between judge 1 and 2 for each column of the knowledge matrix

The columns of the matrix can be analysed in the same way. It holds that the codes of both judges, which belong to the same column, are taken into account. For instance, codes of both

judges for the same learning experiences within the column of basic knowledge (categories 1.1, 2.1, 3.1 or 4.1) are compared. The results for each row are presented alongside.
By this approach a proportion of 65% from the original table 3.5 is analysed (474 out of 730).

Table 3.7a Basic knowledge

Basic knowl.	1.1	2.1	3.1	4.1	TOT
1.1	182	8	0	1	191
2.1	4	17	1	0	22
3.1	3	1	1	1	6
4.1	6	1	0	3	10
TOT	195	27	2	5	229

Table 3.7b Design knowledge

Design knowl.	1.2	2.2	3.2	4.2	TOT
1.2	61	4	0	1	66
2.2	3	7	0	1	11
3.2	6	1	0	1	8
4.2	1	1	0	8	10
TOT	71	13	0	11	95

Table 3.7c Process knowledge

Process knowl.	1.3	2.3	3.3	4.3	TOT
1.3	75	16	0	3	94
2.3	13	15	1	4	33
3.3	0	0	3	2	5
4.3	6	1	0	11	18
TOT	94	32	4	20	150

Compared to the knowledge types the distribution of codes over the *knowledge components*, the columns of the matrix, are more balanced.
On *basic knowledge* the agreement is 89% (κ=.61). The other 11% of disagreed codes are distributed over all rows.
Design knowledge has a proportion of 80% of agreed codes (κ=.56). Much confusion surrounds declarative and procedural knowledge, while in one direction declarative and situational together are also used for the same learning experiences.
Finally, as to the *process knowledge* the proportion of agreement is 69% (κ=.44), while the codes outside the diagonal are mainly in the cells combining 1.3 and 2.3 (declarative and procedural knowledge).

In summary, within each column the confusion between the cells is considerable, mainly between declarative and procedural knowledge. The overlap is summarized in figure 3.2. By reducing the original categories, i.e. combining the cells in each column, we increase the proportion of agreed codes from 52% to 65%. In our opinion this remaining portion of codes is sufficient to carry out a further analysis with respect to the content knowledge.
Though, because of this reduction, a 35% loss of the learning experiences is incurred and hence it is difficult to expect statements on an individual level. Therefore, results will be grouped together in order to draw reliable conclusions.

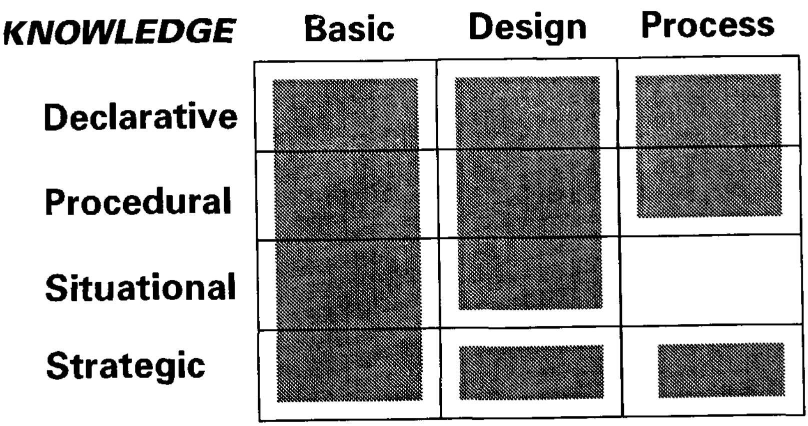

Figure 3.2 Overlap per column

In the following section the results are based on the reduced data.

Knowledge development during the year

Analysis of the subjects development as regards the type of learning experiences observed during the 12 month period (figure 3.3) shows that, except for the second half of the fourth project, basic knowledge is mentioned most frequently early in the year and decreases to the end. Design knowledge increases gradually. General process knowledge also shows a significant rise over the year, but again except for the second half of the fourth project. This lull can be explained by the particular character of this part of the design project. Roughly speaking every design project runs more or less through every stage of a set design process: programming, data collection, analysis, synthesis, development and communication (Archer, 1963). The fourth project takes two terms, each covering one half of the project. The first half concerns the stages of analysis and synthesis: problem finding, idea generation etc., leading to a design concept. The second half of the project stresses basic and design knowledge and skills: making technical and presentation drawings, constructing a prototype

and finishing a design report. This might account for the discontinuity in the codes within the fourth project.

In order to compare the fourth project with the previous projects figure 3.4 shows the same results when all codes in the fourth project are added and proportionally adjusted. The increase in process knowledge seems to confirm the aforementioned theoretical notion that the outcome of the learning process is the acquiring of higher-order rules that are capable of being generalized in a wide variety of stimulus situations.

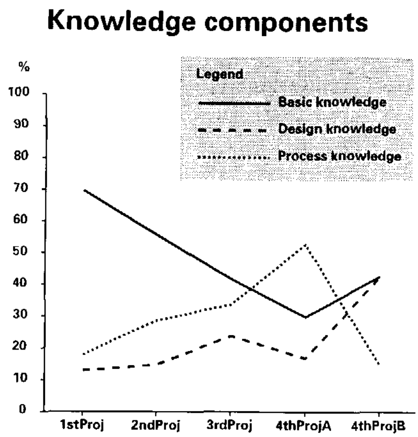

Figure 3.3 Knowledge development

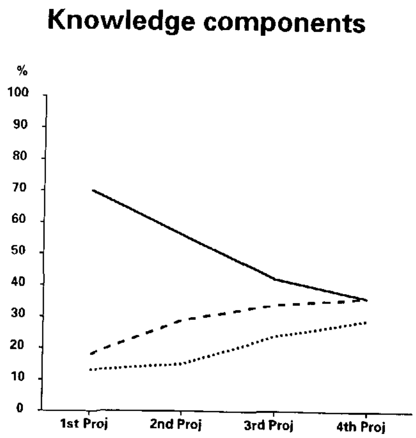

Figure 3.4 Knowledge development

Relationship creativity - knowledge base

The product-moment correlation between each knowledge component (basic, design and process knowledge) and the product creativity rating (PCR) can shed some light on relationship between knowledge of the subjects, acquired during the design project, and the creativity of their product. Measurement of knowledge was based on the amount of agreed codes within each component (see tables 3.7a to c); PCR for each subject was measured by the consensual assessment technique (see procedure of this study). In order to investigate whether a possible relationship is really dependent on creativity, the correlation was also measured between knowledge components and the extreme PCR-scores (High-Low, HL). As HL-criteria average PCR-scores ≥ 6 and ≤ 4.5 are used. Table 3.8 shows the results.
Although none of the coefficients are significant ($\alpha = .05$), two findings are of special interest. Firstly, the correlation of .34 and .41 between creativity and process knowledge indicates that, according to the reports, subjects who design the most creative products acquired more process knowledge than other students. This finding could possibly insinuate that designing more creative products is partly dependent on the application of process knowledge. In appendix III examples of the general process knowledge are presented.
Secondly, the correlation of .41 between basic knowledge and design knowledge is striking. An explanation is not obvious, except that both are defined as 'domain-specific' (fig. 3.1).

Table 3.8 Product-moment correlations between knowledge components and Product creativity ($N_{HL}=9$)

Knowledge components + PCR	Basic knowledge	Design knowledge	Process knowledge	PCR	HL PCR
Basic knowledge	-				
Design knowledge	.41	-			
Process knowledge	-.26	-.01	-		
PCR (crea)	.01	-.10	.34	-	
HL PCR	-	-.15	.41	.87	-

3.6.3 *Discussion*

In the present study an attempt is made to establish what knowledge may be relevant to the designer. On the basis of categorizing knowledge in a three-by-four matrix, the learning experiences of a group of first-year design students were analysed. Moreover, a creativity criterion was used to account for differences in behaviour by differences in knowledge elicitation.
Although experiences verbalized in learner reports are in no way a measure of what the student really knows at a particular moment, in a relative sense they can provide important information about the increase in knowledge during the design project and during the year.

An aim of study I was, therefore, to test the validity of the knowledge matrix as an analytic instrument, and to determine the usefulness of learner reports as a knowledge-elicitation technique.

Method

The methodological analysis reveals that the four learner report encoders are not very reliable. The disagreement between the encoders in categorizing the learning experiences is dependent on three features, the idiosyncratic encoding tendency of the judges, the complexity of the knowledge matrix, and the content of the written material.
The professional background of the encoders is a fundamental and very important cause of the disagreement in that both design teachers interpret the categories of the matrix in a very different way. They probably find it difficult to break away from their educational practice, thus interpreting the written experiences accordingly. On the other hand, the two psychologist encoders were in much closer agreement. And hence the further analysis was based on only their codes.
Strikingly, as far as the knowledge matrix was concerned, almost 80% of the learning experiences were encoded as *declarative* knowledge. Consequently, further detailed analysis of the knowledge types (the rows of the matrix) was not fruitful. Additional analysis of the knowledge components (basic, design and process knowledge; the columns of the matrix) showed that a reduction of categories within each component could raise the reliability of the codes.

Knowledge acquisition

The results of the knowledge classification show that first-year students report knowledge mainly on a declarative level. This can be explained partly by the undoubted problem of eliciting knowledge of procedures, situations and strategies. These knowledge types are mostly automatized and therefore no longer available in conscious memory. However, other explanations are possible too. Even in a 'learning-by-doing' situation the learning of procedural, situational and strategic knowledge is not guaranteed if these aspects are not stressed as very relevant residuals of learning.
The acquisition of knowledge by the novice designer in the design projects through the year is investigated by observing the development of basic, design and process knowledge. Regarding domain-specific knowledge, the reported basic knowledge decreases while design knowledge increases. The domain-independent process knowledge also increases through the year. The data seem to confirm the assumption expressed before, that, by performing design projects during the year students acquire general process knowledge, heuristics and probably higher-order rules that can be applied in a wide variety of stimulus situations. Hence, in their learning experiences students stress more and more the acquisition of this kind of knowledge, while the amount of basic knowledge in their learner reports decreases.
In design project IV the difference between the first and the second parts concerning the contribution of the three knowledge components, can be seen as validation for the measuring

instrument. It differentiates between two parts of the design project which initially could not be distinguished on face value.
Also, a consequent reduction of the knowledge matrix to only three components meant that another important form of knowledge, defined as *strategic* knowledge, merged into these components. The view of Venselaar et al. (1987) was that strategies are component-related. For example, knowledge of an algorithm in mechanics can be described as a strategy on a 'basic knowledge' level; often these strategies are defined as strong methods. On the other hand knowledge of heuristics in solving ill-defined problems, so called weak methods, should be described as general process knowledge.
However, nearly all learning experiences in the study conducted here, coded 4.1 or 4.2 ('basic knowledge'strategies and 'design knowledge'strategies respectively), express weak methods. Examples are presented in appendix III. A suggestion for a follow-up study, if again most codes are on a declarative level and if the learning experiences coded as such express weak methods, could be to add strategic knowledge to general process knowledge.

Creativity

The data indicate that the amount of domain-independent process knowledge elicited is related to the product creativity rating. Students with a high PCR report more process knowledge. The question is whether the correlation coefficients of .34 and .41 between PCR and the amount of process knowledge reported really indicate that students, who acquired process knowledge like higher-order-rules, are better able to design creative products. A rival hypothesis could be that creative students are better able to elicit process knowledge.

The study reported here was started in order to explore knowledge categories applied in solving design problems. The results so far are of course tentative and have to be confirmed by further research. A number of questions are still open:

- Can the reliability of the encoding technique, in terms of the agreement between encoders, be increased while using the same knowledge matrix?
- Are learner reports suitable for eliciting knowledge acquisition, i.e. do they provide a relatively reliable picture of what is learnt by the students? The reliability can presumably be increased by asking students to write learner reports more frequently.
- There is seemingly a positive correlation between the creativity score and the amount of process knowledge elicited. Will this result be confirmed in a replication study, and what about cause and consequence?

In a follow-up study there is the opportunity to strengthen the tentative conclusions of the first study. Although the criticism on the applied method is rather strong, it's too early to reject this method.

3.7 *Study II*

3.7.1 *Method*

Subjects

Involved in the second study were freshmen at the School of Industrial Design Engineering enroling in the 1988/1989 yeargroup. The total 240 freshmen population was subdivided into four groups, each with their own time-table. Two of these groups were randomly selected to participate in this second study. By selecting complete groups it was easier to administer an extra task. This task was the writing of learning experieces both midway and at the end of each design project.
As in study I only students with a 'VWO' schooling background were taken into the sample. During the first year three other factors were responsible for a further reduction of the sample:
- In an educational setting part of the population will drop-out during the course.
- In the analysis per design project only subjects who undertook both learner reports, midway and after completion of the project, were considered. However the control on this task by the design staff was not undertaken strictly; hence, not all students wrote both reports during each project.
- In design project V one of the two groups which were part of the sample, did not write learner reports midway through the project.

The sample size in each design project is stated in table 3.9.
To investigate the relationship between knowledge and the quality of design, products designed by the students in three of the five projects were used. Because of the need to record the subject's designs, slides were made by the design staff. These slides were used in the study to assess the designs on different criteria. However, because of technical errors not all products were recorded. Moreover, the quality of some slides was so poor they were rendered useless. In the analysis of each separate project only the data of subjects with complete records - two learner reports and a slide of the design - were examined. In the three design projects analysed in this study, the number of subjects were respectively 55, 35 and 30. See also table 3.9.

Design course

The design course in 1988/1989 differed from the 1985-course, as explained in study I. Instead of the extensive fourth project in the 3rd and 4th quarters of the year, two separate projects were introduced by the design staff. These projects IV and V took 6 weeks each. Moreover, both new projects were performed individually. One fundamental reason for this change was to be better able to assess students on their personal design qualities. A second reason had to do with the effectiveness of the learning process, the lengthy project of twelve weeks was assumed by the staff to be less effective than two short projects of half the duration. This was also suggested by the results of study I.

As regards the creativity assessment, only the outcomes of the individual projects were taken into account: projects III, IV and V. The design brief of project III was to design a public 'telephone booth', the same brief as in 1985. In project IV students had to design a 'shop-window display', and in project V a 'drill holder'. Examples of these designs were presented in chapter 2.

Learner reports

Students in the sample were asked to write their learning experiences midway and at the end of each project. The first report was written after the conceptual stage, including problem finding and idea generation, leading to a design concept. The second report, after completion of the project, was mainly concerned with the concept elaboration: making technical and presentation drawings, constructing a prototype and finishing the design report.
The same instruction for writing a learner report was used as described in study I. A report consisted of three parts: an introduction to the design brief, the learning experiences, and the consequent actions on what had been learnt.
Table 3.9 presents a summary of the data mentioned before: time-schedule of each design project, number of sessions per week, designing within groups or individually, moment of writing learner reports, and number of subjects.

Table 3.9 Some characteristics of design projects during the first year

	1st Quarter		2nd Quarter	3rd Quarter	4th Quarter
Project	I	II	III	IV	V
Weeks Sessions/week Group/Individual	2 1 g	4 1 g	6 2 i	6 2 i	6 2 i
Learner report A = midway B = end N (subjects)		A B 86	A B 97	A B 69	A B 45
Product assessment (pa) N			 pa 55	 pa 35	 pa 30

Transcription of learner reports

Again from the learner reports only part 2, the learning experiences, was used in the knowledge analysis. While in the first study the encoders segmented the reports into separate experiences, here one of the encoders performed this task, using the criteria as in the first study; i.e. starting a new line of encoding with a full stop after a sentence or with more sentences which clearly belong together (see also encoding procedure).

Encoding procedure

Encoding of learner reports was accomplished by two encoders, the two psychologists from study I. They encoded all learner reports using the same encoding rules, reported in study I (see also boxes 3.1 and 3.2).
However the encoding method differed substantially.
In order to increase the objectivity of the procedure the assistance of a computer was enlisted to help with encoding.
A computer program, named NOMSCORE [4], was developed to code each separate learning experience without revealing the name of the subject, the project to which it refers or the other experiences of the same subject. As figure 3.5 shows, the screen only presents one experience. The encoder then gives a code after which the next screen, with a new experience, is presented. The numbers at the top are respectively the row number of this particular experience and, between brackets, the total number of experiences in the file to be encoded.
Beforehand the reports were typewritten, and prepared in a way that suited the requirements of the program.

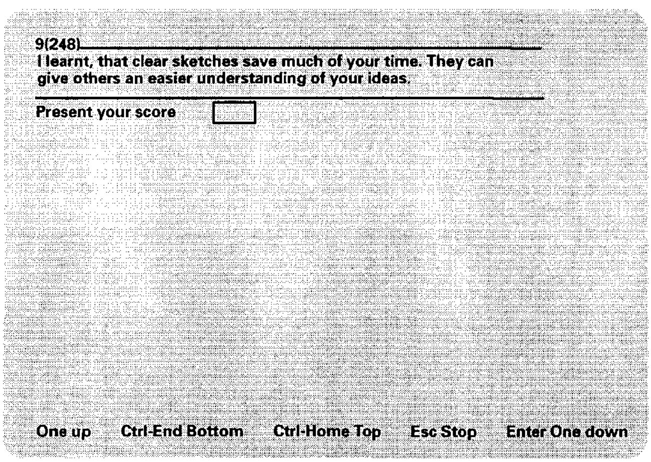

Figure 3.5 NOMSCORE screen

The reports of each design project were recorded on separate files. An 'outsider' mixed the two files, so encoders were unable to distinguish between them. The encoders could undertake the task wherever they preferred as long as they worked strictly individually. After all the learning experiences of both files were encoded, NOMSCORE separated the files again

[4] The NOMSCORE program was developed by Mark de Hoogh, Delft University of Technology, School of Industrial Design Engineering

and produced a list of the encoders codes side by side. From these lists frequency tables could be made and inter-encoder agreement derived.

Creativity measurement

A detailed description of the procedure of creativity assessment is presented in chapter 2, study III. Creativity scores were obtained from subjects in design project III (N=55), IV (N=35) and V (N=30). In order to give a score for the creativity of each subjects designed product, a 'Product Creativity Rating' (PCR) was defined by averaging the creativity scores of the 10 judges involved in the creativity study.

3.7.3 *Results*

Inter-encoder agreement

Measurement of the inter-encoder agreement was done separately for each of the design projects, based on both midway and end reports.

Table 3.10 Agreement between judges *in encoding knowledge categories; learner reports IIIA*

IIIA	Judge 1												
Judge 2	1.1	2.1	3.1	4.1	1.2	2.2	3.2	4.2	1.3	2.3	3.3	4.3	TOT
1.1	**88**	14	14	8	7	1	-	2	17	1	-	1	153
2.1	2	**18**	5	2	2	-	-	-	2	3	1	-	35
3.1	2	4	**2**	-	-	-	1	-	-	1	1	-	11
4.1	3	3	1	**12**	-	-	-	4	1	-	-	1	25
1.2	12	-	3	-	**19**	2	3	2	13	5	4	-	63
2.2	-	-	1	-	2	**5**	-	-	1	2	-	-	11
3.2	-	-	-	-	2	1	**-**	1	1	-	-	-	5
4.2	1	3	1	3	-	-	-	**11**	2	2	-	5	28
1.3	4	-	1	-	5	1	-	-	**54**	22	1	3	91
2.3	1	-	-	-	1	-	1	1	11	**23**	-	-	38
3.3	-	-	-	-	-	-	1	-	3	1	**-**	-	5
4.3	-	-	-	1	-	-	-	-	-	2	1	**3**	7
TOT	113	42	28	26	38	10	6	21	105	62	8	13	472

In order to compare the results with the first study a similar analysis was performed. As an illustration only two projects, chosen at random, are presented here, project III 'half-way' (IIIA), and (in short) project IV 'end' (IVB). In table 3.10 the complete matrix of IIIA is shown.

- The encoder agreement, as defined by coefficient kappa, is $\kappa=.41$; the proportion of agreement (values on the diagonal) is 50%. These findings correspond to study I.
- The marginal totals differ significantly again ($\chi^2=54.1$; df=11; $p<0.001$).
- The proportion of codes in the *declarative* knowledge categories (1.1, 1.2, and 1.3) is 54% for judge 1, and 65% for judge 2; in procedural knowledge resp. 24 and 18; in situational knowledge resp. 9 and 4; in strategic knowledge 13 and 13.

Agreement for each row of the knowledge matrix

Once again, the codes of both judges are taken into account if they both belong to the same row (see study I). By this approach a proportion of 67% from the original table 3.10 can be analysed (315 out of 472 codes).

Table 3.11a Declarative knowledge

Declar. knowl.	1.1	1.2	1.3	TOT
1.1	88	7	17	112
1.2	12	19	13	44
1.3	4	5	54	63
TOT	104	31	84	219

Table 3.11b Procedural knowledge

Proced. knowl.	2.1	2.2	2.3	TOT
2.1	18	0	3	21
2.2	0	5	2	7
2.3	0	0	23	23
TOT	18	5	28	51

Table 3.11c Situational knowledge

Situat. knowl	3.1	3.2	3.3	TOT
3.1	2	1	1	4
3.2	0	0	0	0
3.3	0	1	0	1
TOT	2	2	1	5

Table 3.11d Strategic knowledge

Strateg. knowl.	4.1	4.2	4.3	TOT
4.1	12	4	1	17
4.2	3	11	5	19
4.3	1	0	3	4
TOT	16	15	9	40

In general most coded learning experiences - 70% - are within the row of declarative knowledge. Within this declarative row 74% of the codes are in agreement, while the distribution of the other codes are scattered over all three columns (κ=.57). Within the procedural row most codes are on the diagonal (κ=.84).
Situational knowledge is hardly mentioned, while the procedural and strategic categories also have too few codes to draw reliable conclusions (κ=.06 for situational, and .44 for strategic knowledge. Only when these three rows are taken together further analysis seems possible.

Agreement for each column of the knowledge matrix

The codes of both judges are taken into account if they both belong to the same column. Hence a proportion of 74% from the original table 3.10 can be analysed (350 out of 472 codes).
Compared to the four knowledge types declarative, procedural, situational and strategic) the distribution of codes over the *knowledge components* (basic, design and process knowledge) is more balanced.

Table 3.12a Basic knowledge

Basic knowl.	1.1	2.1	3.1	4.1	TOT
1.1	88	14	14	8	124
2.1	2	18	5	2	27
3.1	2	4	2	0	8
4.1	3	3	1	12	19
TOT	95	39	22	22	178

Table 3.12b Design knowledge

Design knowl.	1.2	2.2	3.2	4.2	TOT
1.2	19	2	3	2	26
2.2	2	5	0	0	7
3.2	2	1	0	1	4
4.2	0	0	0	11	11
TOT	23	8	3	14	48

Table 3.12c Process knowledge

Process knowl.	1.3	2.3	3.3	4.3	TOT
1.3	54	22	1	3	80
2.3	11	23	0	0	34
3.3	3	1	0	0	4
4.3	3	1	0	0	4
TOT	68	48	2	6	124

In the column of *basic knowledge* the proportion of agreement is 67% (κ=.43). The other 33% of disagreed codes are distributed over all rows.
Design knowledge has a proportion of agreed codes of 73% (κ=.58). The remaining codes are scattered over all rows.
Finally, as to the *process knowledge* the proportion of agreement is 65% (κ=.29), while the codes outside the diagonal are mainly in the cells combining 1.3 and 2.3 (declarative and procedural knowledge).

In summary then, the overall image of the IIIA code distribution does not differ much from that of the first study, except that within the column of design knowledge the confusion between the cells is smaller.
The same analysis regarding the codes of project IV-B gives nearly the same results. In appendix IV the table with all codes of the two encoders is presented. The proportion of agreement (values on the diagonal) is 38%. Looking at the agreement with regard to declarative, procedural, situational and strategic knowledge, 67% of the codes (220 out of 330 codes) could be analysed. Again, most codes (75%) are within the declarative knowledge row. But here only 53% of the codes are agreed upon. For both reasons the the rows are not useful for further analysis. With regard to the columns of the IVB matrix (basic, design and process knowledge) 57% of the codes (188 out of 330 codes) can be analysed. The proportion of agreed codes regarding basic knowledge is 64% (43:67 codes), design knowledge 69% (58:84 codes), and process knowledge 70% (26:37 codes).

Conclusion

Firstly, the overall conclusion is that the results of study I with regard to inter-encoder reliability are confirmed here. The disagreement is too large to use the matrix on the level of separate categories. Further analysis shows that a reduction of the original categories can be found in combining the cells in either each row or each column. The problem with using rows is that three of the four rows, i.e. procedural, situational and strategic knowledge, are poorly filled. Therefore, it was decided to use again the columns of the matrix. This reduction increases the proportion of agreed codes to an acceptable level.
Secondly, the suggestion of study I to combine the row of *strategic* knowledge with the column of *process* knowledge was adopted here. The idea was, from a theoretical point of view, that the categories belonging to both kinds of knowledge have much in common. Moreover, in most of the projects the encoders showed confusion between these two kinds of knowledge, and also between the three categories belonging to the row of strategic knowledge.
The proportion of the agreed column codes throughout the different projects, including the combination of strategic knowledge and process knowledge, ranges from 59% to 77%. Due to the loss of a considerable amount of written learning experiences, statements are not made on an individual level.

Thirdly, for the same reason the codes of the reports midway and at the end of the project are combined. Moreover, this sum score will make possible a comparison with the results of study I.

Knowledge development during the year

Figure 3.6 shows the development of three knowledge components during the year. As for study I (see fig. 3.4) basic knowledge is mentioned most frequently early in the year and decreases toward the end. Design knowledge increases gradually, while general process knowledge, including strategic knowledge, shows only an initial increase.

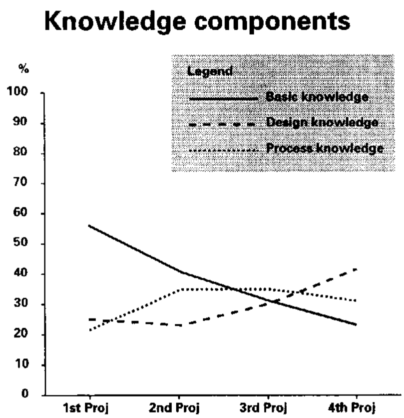

Figure 3.6 Knowledge development

Relationship creativity - knowledge base

Correlations between the three knowledge components (basic, design and process knowledge) and the product creativity rating (PCR) are measured separately for the three design projects. In project III the product was a telephone booth; the creativity of these products was related to the knowledge codes of project III. In line with this characteristic, the creativity of the 'shop-window display' was related to knowledge codes in project IV, while the drill container was related to knowledge codes of project V. Again the correlation was measured between knowledge codes and the extreme PCR-scores (High-Low). As HL-criteria average PCR-scores ≥ 6 and ≤ 4.5 are used. Tables 3.13a to c show the results.
Although none of the coefficients are significant ($\alpha = .05$), in the three projects a positive correlation can be observed between creativity and domain-independent process knowledge.

In appendix III examples of process knowledge experiences are presented.

Table 3.13a Product-moment correlations between knowledge components and Product creativity; project III (N=55)

Knowledge components + PCR	Basic knowledge	Design knowledge	Process knowledge	PCR	HL PCR
Basic knowledge	-				
Design knowledge	.10	-			
Process knowledge	-.21	-.04	-		
PCR (crea)	.23	-.20	.14	-	
HL PCR	-.10	-.25	.20	.94	-

Table 3.13b Product-moment correlations between knowledge components and Product creativity; project IV (N=35)

Knowledge components + PCR	Basic knowledge	Design knowledge	Process knowledge	PCR	HL PCR
Basic kn.	-				
Design kn.	-.43	-			
Process kn.	-.33	.10	-		
PCR (crea)	-.40	-.03	.31	-	
HL PCR	-.24	-.52	.45	.93	-

Table 3.13c Product-moment correlations between knowledge components and Product creativity; project V (N=30)

Knowledge components + PCR	Basic knowledge	Design knowledge	Process knowledge	PCR	HL PCR
Basic kn.	-				
Design kn.	.29	-			
Process kn.	-.19	.13	-		
PCR (crea)	-.06	.05	.39	-	
HL PCR	.08	.13	.47	.90	-

3.7.3 *Discussion*

This second study was again focused on exploring the role of knowledge in design. What knowledge is acquired by students during the first-year design courses, and what is the relationship between kinds of knowledge acquired and the design solutions generated? Written learning experiences were the data analysed. Retrospective reports can only meaningfully be

used if the utterances of the students can be encoded reliably according to one or another encoding method. The reliability of the method is dependent on the agreement encoders show in using this method. In this second study a knowledge classification from the first study was again used. In the first study the results showed that the classification was still open to doubt. The lack of reliability, highlighted by the considerable amount of disagreement between encoders, made it impossible to analyse knowledge acquisition on a detailed level for twelve separate categories. Hence the matrix was reduced to only three overall knowledge components, i.e. domain-specific basic and design knowledge, and domain-independent process knowledge. In study II this methodological problem was also faced. Again, the agreement in this study between the encoders is too low, even though both had experience in performing the task. As a matter of fact, the reason for the low reliability of the method must be sought in either the classification system itself or in the data encoded. The knowledge classification is a rather complex process, in that the boundaries of the categories are rather vague. But also the learning experiences are written in such a way that many interpretations are possible as to what knowledge category each experience belongs. A reduction of the original knowledge classification to three knowledge components, i.e. basic knowledge, design knowledge and process knowledge, was the only acceptable compromise. By this approach the proportion of learning experiences was reduced to 59-77%, which was enough to be able to draw reliable conclusions. On the other hand, a reduction of the four rows of the matrix, declarative, procedural, situational and strategic knowledge, was not meaningful because most of the learning experiences were encoded as declarative knowledge while situational and strategic knowledge were hardly elicited.
Because of the reduction in the number of codes and categories, most conclusions were drawn on group level.

The results of this second study regarding knowledge analysis confirm the results of study I. Firstly, over 70% of the learning experiences can be classified as *declarative* knowledge; knowledge of facts. It seems almost impossible to elicit in retrospect, knowledge of procedures and problem situations, especially if this procedural and situational knowledge are highly automated. Secondly, relating the creativity of the students designs with elicited knowledge from three projects reported throughout the year, shows a positive correlation between creativity and amount of general process knowledge obtained. Although the coefficients are not significant, there is an obvious trend between the first and second studies. What is the meaning of this relationship? Process knowledge was defined as *domain-independent* knowledge related to the monitoring function of memory that helps the problem solver to organize and evaluate the problem-solving process as a whole. A tentative conclusion could be then that students who have acquired this process knowledge, and are guided by it (as suggested by the fact that they are able to reflect on this kind of knowledge in their learner reports) are better able to generate creative solutions. Knowledge of weak methods will possibly be important during the first year because an adequate knowledge base is still lacking; strong methods, if applicable at all in the domain of designing, do not yet belong to the repertoire of novice designers. The data in this study do not allow however, for a more rigurous conclusion.

Overall, the encoding method failed again to offer a refined method for knowledge analysis. A simpler classification is probably more reliable, but would lead to a loss of detailed information on knowledge acquisition. If learning experiences will be used as real verbalizations of knowledge acquisition, rules has to be developed as to how the experiences must be written in order to fulfill the wishes of the researcher. Moreover, a further requirement related to retrospective reports as data is, that they must be written or verbalized soon after the problem solving task.

3.8 *General discussion*

The purpose of design education is the transfer of knowledge for solving design problems in such a way as to prepare students for their development and promotion from novices to design experts. As a matter of fact, little is known about the way in which knowledge and skills within this domain are actually acquired and used. The aim of this and further research is to find explicit, detailed knowledge of the design engineering process as a whole, with special attention paid to product- and process-related knowledge. An understanding of the kind of knowledge a designer needs during the design process would form an important contribution to problem solving in general and design education in particular. The next step is then to find out the learning situation to be met in order to teach and learn this knowledge effectively and efficiently.

The studies in this and the next chapter have two objectives; firstly, to derive an understanding of the design process through an awareness of its knowledge components; in doing this to investigate the relationship between knowledge and design quality, and to see whether the quality of the outcome, i.e. the solution, is dependent on the quality of the process. And secondly, to find adequate methods for analysing both design knowledge and design quality. On both topics research within the domain of industrial design engineering is sparse. Hence, the research project carried out here started with studies regarding creativity as a criterion for design quality, as is described in chapter 2. The next step in the project found attention being paid to methodological issues regarding the measurement of design knowledge. Two research methods were introduced to investigate design students knowledge. The first one was based on retrospective, written 'learner reports' of first-year students. A knowledge classification was used, developed by Venselaar et al. (1987), in order to encode the reports. The second method, based on concurrent verbal reports by 'thinking aloud' protocols, is described in the next chapter.

What are the conclusions regarding the reliability and validity of knowledge measurement by the first method, that is, the use of retrospective reports together with a refined classification system?

Method

The use of the knowledge classication system encountered many problems which were not foreseen.

First, methodological analysis showed that the encoders of the learner reports were not very reliable judges. The best result was obtained by the two psychologist encoders, with a proportion of about 50% agreement. Disagreement between encoders was due to individual idiosyncracies on the part of the encoders, to the complexity of the knowledge matrix, and also to the content of the written material.
The second study proved that performance improvement in inter-encoder reliability is very difficult. Apparently, the classification system is too difficult to handle, because it gives too much room for confusion.
As to the validity of learner reports there are two main disadvantages. Firstly, most of the reports are written after the students have finished their project. Some projects took 6 weeks, so what is remembered may be unreliable, i.e. do these reports contain superficial data, or just detailed high-lights? Secondly, even if the experiences elicited are reliable, they represent only a small part of knowledge acquisition. Nevertheless, even this small part can be of value when used in a relative way, comparing between subjects from a large sample.
Looking at the content of the reports, almost 80% of the learning experiences were encoded as *declarative* knowledge. As a consequence, a further detailed analysis of knowledge in terms of procedures, situations, and strategies would not have been fruitful. Only the knowledge components, defined as domain-specific and domain-independent knowledge (the columns of the knowledge matrix) could be used.

Content analysis

There are however also positive results, which make the studies conducted here valuable. Firstly, although the inter-encoder reliability is not high, there are a certain amount of learning experiences (about 50%) on which there is agreement. Based on these data reliable conclusions could be drawn with respect to the development of part of the knowledge acquisition during the year, and to the relationship between the same knowledge acquisition and the creativity of the design solutions.

Firstly, the learning experiences show that during the year students stress more and more the learning of general process knowledge, while domain-specific basic knowledge looses attention. This result is similar in both studies. A preliminary assumption being that by doing design projects during the year students acquire general process knowledge, in terms of heuristics and higher-order rules.
Secondly, in nearly all separate design projects, within both studies, a relationship was found between the creativity of the design and the amount of process knowledge elicited. Although the correlation is not significant, there is a consequent tendency for subjects whose designs are rated creatively higher to elicit on average a greater amount of general process knowledge than other students. Some rival hypotheses could be infered from this finding, even though they are speculative. The tendency could mean that novice designers who design creative products have already acquired certain expert qualities; i.e. they possess well-organized abstract knowledge in terms of underlying principles (Anzay, 1991). Another hypothesis is that better designers are better able to reflect consciously on their acquired domain-

independent knowledge. A counter-argument here being, that in these studies the same students do not design creative products all the time; for example the product of a student designed in project 1 is rated as very creative, while the products of the same student in projects 2 and 3 get an average score. So, the relationship between creativity and amount of general process knowledge is not only person-related.
The same finding of variance in creativity per person can also indicate that the design task itself has influence on the performance quality, related to the commitment of the designer they evoke.

The overall conclusion is that the method of knowledge measurement deserves further development. Firstly, a better definition of knowledge categories, together with a simpler way of encoding would improve the current classification. Secondly, the method used in elititing knowledge from (novice) designers by way of retrospective reports leaves much to be desired. Another elicitation technique for further research should be recommended, so that what the designer is doing, and what knowledge he/she is using can be more directly defined.
Finally, the studies described here provide some interesting, but still speculative, results with regard to the development of knowledge acquisition during the year, and to the relationship between knowledge and performance quality. In order to explore in more detail both aspects of expertise, further research has to conducted. Together with introducing another elicitation technique it would be valuable to investigate additionally differences in expertise by comparing novices and experts in designing.
The study described in the next chapter can be viewed as a parallel study to the ones described here. The same research questions underly this research project. The most important difference being the elicitation method used, i.e. protocol analysis. Moreover, together with novice designers students with intermediate level of expertise will be involved. Again, it is important to realize that the aim of the next study is to explore the relationship between domain knowledge and performance quality in design.

Chapter 4 Expertise in design; a protocol study [5]

4.1 *Introduction*

Within the studies so far, descriptions have been made of the design process as a learning process by which domain-specific content knowledge and general process knowledge, both belonging to the domain of industrial design, are acquired during design projects. In order to explore the relationship between the kind of knowledge used and the quality of the output of the design process, retrospective written reports were encoded according to a matrix of 12 knowledge categories. However, the system of encoding by way of this classification only partially provided reliable and valid measures. The classification into declarative, procedural, situational and strategic knowledge, derived from literature on learning theories, was not particularly useful, for three main reasons. Firstly, the encoders produced unreliable measures concerning this distinction, i.e. they often disagreed when using these codes. Secondly, the data confirmed that procedural and situational, or conditional, knowledge is hardly elicited (Anderson, 1987). Thirdly, the data were derived from students, writing learner reports *in retrospect*, i.e. only one or more weeks after they had finished the design project. As a consequence, conclusions as to the relationship between knowledge and performance quality could only be drawn on a rather general level; that is to say, the results of the studies showed that the distinction between domain-specific knowledge (basic knowledge and design knowledge) and general process knowledge was meaningful as far as the reliability of the encoding system was concerned. A relationship was also demonstrated between the amount of process knowledge reported and the creativity of the artifact produced.
Although these findings indicate the importance of certain knowledge to be used in designing, the nature of the reports and the superficiality of the knowledge classification does not allow for a more detailed description of the role of knowledge. Hence, retrospective reports of design projects, as used here, are only suitable for an initial, rough, indication of the extra knowledge acquired by the design projects. A second step in the analysis must be taken in order to investigate the how's and when's of the use of specific knowledge, of problem solving and reasoning strategies, and of evaluation procedures. Therefore, another elicitation technique was adopted, using concurrent reports of subjects. Moreover, because the knowledge classification used in chapter 3 didn't satisfy the study requirements, a new method had to be sought for in order to analyse the relationship between the knowledge

[5] I am grateful for the cooperation of Cees Dorst in conducting this experiment and performing part of the analysis.

involved in designing, and the creativity of the design output. In literature on elicitation techniques *protocol analysis* is described as particularly suited to elicit information concerning the situations described previously (Ericson & Simon, 1984; Breuker & Wielinga, 1984; Schraagen, 1986). By this method, behaviour is recorded as a person works through a problem.
This elicitation technique is now discussed, followed by an exploration into the existing information from protocol studies in design.

4.2 *Designer's expertise*

According to the theory on problem solving by Newell and Simon (1972) problem solving requires an internal representation of an external task environment. A representation consists of data structures and programs which operate on them to generate new inferences (Larkin & Simon, 1987). From the possible internal representations of the problem which may be generated, the subject chooses one or more within which to operate. This notion is part of the 'problem space hypothesis' (Laird et al., 1987). The assumption is that problem solving occurs through searching within one's *problem space*, which is the fundamental organization for all goal-oriented activity. The problem space consists of representations, the information processes, and all knowledge available. The size of the problem space is an important determinant regarding the level of problem difficulty because the problem solver must select from many the correct path from start to goal (Newell & Simon, 1972). This size increases with an increasing level of expertise. The assumption is made that designing is a form of problem-solving with a very specific nature. As was stated in chapter 1, the core features of design ability are, according to Cross (1990), the ability to resolve ill-defined problems, to adopt solution-focusing strategies, to employ abductive, productive, and appositional thinking, and to use non-verbal, graphic/spatial modelling media. In order to understand designing, and thus the role of knowledge in designing, investigations into how experts in design 'do it' are imperative. And, in the same way, if an understanding of how knowledge in design is acquired, a longitudinal study of design students from freshman to graduate seems most appropriate. In order to avoid practical complications of such a study an alternative method could be a cross-sectional comparison of design students with different levels of expertise.

4.2.1 *Knowledge elicitation*

How can information be elicited from designers or design students? Breuker & Wielinga (1984) distinguish a number of techniques for knowledge elicitation from experts.
For each technique, with explanation into the possible handling strategies, they describe what types of knowledge can be expected to be elicited. In table 4.1 an overview is presented.
The *focused interview* is done by way of normal conversation, in which a topic is prepared in advance by the interviewer. In a *structured interview* the interviewer tries to elicit all knowledge related to a certain concept or model by continuously interrogating the expert. By *introspection* the expert is asked to imagine how he/she would solve, or did solve a problem,

or class of problems. Retrospective reporting belongs to this technique. In *self report*, better known as 'protocol analysis', the expert thinks aloud whilst solving a problem. *User dialogue* makes use of the interaction between user and expert. This technique is applied in situations where the problem solving of the expert proceeds in close interaction with the client. Finally, *review* refers to carefully inspecting already elicited data in order to repair gaps in the protocols. Schraagen (1986) adds several techniques to the list, of which sorting tasks and scaling techniques are most important. *Sorting tasks* are used to uncover the knowledge structure of experts. For example subjects are asked to sort out a number of physics problems on the basis of similarities of solution method. *Scaling techniques* are often used to estimate the psychological distances between concepts.

Table 4.1 Elicitation techniques. Strategies and data (After Breuker & Wielinga, 1984; Schraagen, 1986).

Technique/strategy	Data on
Focused interview probing critical incident reclassification symptom to fault intermediate reasoning steps	factual knowledge types of problems functions of expertise environment (objects, agents) user characteristics
Structured interview 20 questions (part of) mental model	structure of concepts reasoning/explanation
Introspection retrospection forward scenario critical incident	global strategies justification evaluation
Self report secondary task selective report	use of knowledge sources heuristics reasoning strategies
User dialogue real life via teletype	user-expert interaction problem 'negotiation'
Review of data of prototype	repair of gaps in data interpretation of data justification
Sorting tasks	knowledge structure
Scaling techniques	network structures of domain concepts

In view of the present research aim, i.e. exploration of the knowledge used in design and the way designers find a solution for the design problem, the technique of self report is most suitable. The designer must think aloud whilst solving the problem. Protocol analysis is a collective noun for analysing subjects verbal reports, reports which can be obtained through a number of different techniques.

The general assumption in using these reports as data is that the cognitive process is similar to information processing. Information is stored in memory, from which it can be retrieved when necessary. According to Newell & Simon (1972) information is stored in several

memories. Information recently acquired is kept in short-term memory (STM), and is directly accessible for further processing. Knowledge in long-term memory (LTM) must first be transferred to STM before it can be reported. They assume that for producing verbal reports the STM is responsible. STM has a limited capacity, so only information that is in the focus of attention, is directly accessible. As the processes involved in certain actions become highly practised, they become automated, i.e. intermediate steps are carried out without being interpreted and without conscious mediation by STM (Ericsson & Simon, 1984). As a consequence the intermediate actions cannot be reported verbally. Therefore, most of the aforementioned knowledge types, such as procedural ('how'), situational or conditional knowledge ('when'), and problem solving strategies must be extracted indirectly. Nevertheless, verbal reports, and more especially problem solvers' concurrent task verbalizations, do reflect a part of the cognitive process.

The reliability and validity of 'think aloud' reports have often been criticized. The following problems are associated with the method (see also Ericsson & Simon, 1984; Shadbolt & Burton, 1990): (1) Subjects have no access to higher-order cognitive processes - especially regarding automated skills -, so the reports are far from complete (Nisbett & Wilson, 1977). Report completeness is also influenced by the skill with which subjects are able to transform non-orally coded information to external speech. (2) A related issue, especially in protocol analysis on solving design (engineering) problems, is the belief that designer's verbalizations cannot reveal those processes that are inherently nonverbal, e.g. geometric reasoning (Finger & Dixon, 1989). (3) Verbalization given concurrently, may interfere with performance. (4) Verbalizations may report an activity that occurs parallel with the actual cognitive process, and is therefore irrelevant. (5) The reports may deliver unstructured transcripts which are hard to analyse.

However, most of these problems, as Ericsson & Simon (1984) state, are not very specific to just this method:

> "Whether one can and should trust subject's verbal reports is not a matter of faith but an empirical issue on a par with the issue of validating other types of behaviour, like eye fixations or motor behaviour." (Ericsson & Simon, 1984, p. 9).

Moreover, the authors conclude, that analysis of the task will often provide strong indications of the adequacy of verbalized information. With regard to the usefulness of the transcripts the authors also state that the objectives of using protocol analysis are clear, and that a coding system for analysing and interpreting the data is available beforehand. The problem of the transfer of nonverbal processes into verbal ones can be avoided if during problem solving subjects are asked to think aloud, write and sketch. These are kinds of external representations which use a set of symbolic expressions to define the problem (Larkin & Simon, 1987), and can be analysed like the other overt responses, expressed both verbally and through gesticulation.

4.2.2 *Conducting protocol analysis*

Shadbolt & Burton (1990) give some suggestions for conducting a protocol analysis study. They state that this kind of study should satisfy a number of preconditions. Firstly, the subject should be sufficiently acquainted with the domain to understand the task. Secondly, problems for the protocol analysis must be selected carefully. An important criterion being that the task is representative of the kind of tasks within the domain. Thirdly, and finally, the subject should not feel embarrassed about describing his/her process in detail. One should give the subject some experience in thinking aloud by one or more training sessions.
Together with the critical remarks mentioned before, these suggestions were integrated within the experimental design of this study.

4.3 *Protocol studies of industrial design*

The first aim of this study was to explore the role of knowledge in what was judged to be a typical industrial design task. Few studies within the specific domain of industrial design can be found in the literature. However, studies in related domains can provide relevant information with respect to the domain of industrial design engineering, e.g. information concerning knowledge sources. Although a general, theoretical discussion of the empirical studies in these related domains is beyond the scope of this chapter, shortly reference to the relevant studies will be made. Next, findings from those studies will be summarized, and consequently tested later in this protocol study.

Most of the research carried out is within the domain of architecture. For an overview of earlier work, see Lera (1981, 1983). More recent studies were performed by Akin (1986), Eckersley (1988), Chan (1990), and Hamel (1990). In these studies theories of cognitive psychology, mainly referring to Newell & Simon's schema theory (1972), are used to describe the architectural design process. In spite of thorough analysis of the protocol data, by way of detailed encoding systems, most studies lead only to general conclusions about object-independent strategies applied by the designer. Because they are not specifically focused on the relationship between the use of domain knowledge and designing, the effect of what and how knowledge is applied is only indirectly referred.
Another related domain in which a number of protocol studies are performed, is the domain of mechanical engineering. Overviews of these studies are provided by Stauffer & Ullman (1988), and by Finger and Dixon (1990). Both overviews lead to some interesting conclusions. As far as the role of knowledge is concerned Stauffer and Ullman discuss the dependence versus independence of design on specific domain knowledge. They oppose the authors of prescriptive design models who present the process as independent of the domain knowledge and who believe that general heuristics and strategies are of decisive importance. Instead, the conclusion based on the studies reviewed is that even a number of heuristics, applied by the designer, are domain-specific. In reviewing literature Finger & Dixon conclude that most studies within mechanical engineering design are set up to investigate a few well-defined questions. A common, general, theory is still lacking, or, as Dixon (1988) states, design research is still in a pre-theory stage, causing some chaos in research. More recent

studies by Ullman et al. (1988), Kuffner & Ullman (1991) and McGinnis & Ullman (1990), motivated by the realization of better computer-aided design tools, show clearly the uncertainty on what to conclude from elicited data.
In short, most studies on the design process are mainly data-driven in that a strong design theory is still missing. To interpret data from the observation of a designer most researchers fall back either on prescriptive models for design, or on cognitive theories as to problem-solving in general. However, from the studies, data regarding the role of knowledge in design can be used to validate and interpret some of the data found in this study.
The literature concerning studies in the two aforementioned design domains is discussed below.

4.4 *Issues in observing designing*

The topics considered fundamental in studying the design process relate to the designer's decision making, his strategies, and the representation techniques used (e.g. sketching). These topics are now successively dealt with.

4.4.1 *Decision making*

In most studies designing is understood as a form of decision making. Lera (1981):

> "A typical design problem is introduced and analysed in terms of its dominant attributes and their relative values. (-) In designing (-) the designer, whether explicitly or not, is making value judgements about the relative importance of the attributes." (Lera, 1981, p. 19).

Through the assumption that designing is a problem-solving activity some authors characterise the decision making process as a sequence of states and transformations. Design problems have an initial state which is usually described in the design brief, states are transformed into other states using operations that are implicitly or explicitly represented in the form of knowledge. Search strategies are employed by the designer to minimize the number of transformations necessary for reaching solution states. Akin (1986) mentions several categories of operations involved. (1) projection of information: inference, interpolation, or deduction from existing information; (2) acquisition of information: from the external environment as well as from memory; (3) representation of information: after acquisition or after internal processing; (4) confirmation of newly acquired or projected information: verification of its consistency against existing information; and (5) regulation of flow of control: reduction of the search space of the designer. Wade (1977) also assumes that the design process is characterized by the transformation of information. First, the designer transforms information about the user and his or her goals into information about behaviour. Next, this information about behaviour is transformed into information about functions, and finally to information about objects, i.e. the design.
Ullman et al. (1988) defined ten kinds of operators, split into three groups: generation operators, evaluation operators, and decision operators. The first group consists of generating design proposals, constraints, or strategies. The evaluation operators serve to relate or

compare information from the design state in order to make a decision. The decision operators are invoked once an evaluation is made.
With regard to the relationship between decision making and performance quality Simmonds (in Lera, 1981) concludes from his protocol studies that the students who produced the most successful design projects, exhibited greater range and flexibility in their decision making strategies.
However, from these descriptions it is still unclear how designers reach their decisions, and what information is important in taking those decisions. In other words, this particular study must be more explicit on the topic. Therefore, it will look at what is known about (1) decision-making strategies, and (2) two attributes of the design problem about which value judgements are made, i.e. constraints and requirements.

4.4.2 *Constraints*

Together with proposals or ideas, constraints are very influential in decision making. Constraints are defined in this study, with regard to features of the design or the design context, as requirements, specifications, statements and value judgements. They can be viewed as limits on the form or function of the design (Ullman et al., 1988). Constraints are derived from the design brief, from the designer's own knowledge of the domain, and from extra information assimilated during the design process. As Chan (1990) states, design constraints are introduced in order to reduce the large problem space for solution generation. Most design processes start with the formulation of constraints, which continues throughout the activity. Ullman et al. (1988) distinguish three ways in which constraints are developed: (a) they are *given*, e.g. in the design brief or in other external information, (b) they are *introduced* by the designer, or (c) they are *derived* during problem solving as a consequence of design decisions. Few studies studies on the role of constraints are mentioned in literature. McGinnis & Ullman (1990) are the only researchers found who conducted a study focused on the development of constraints in a mechanical design task. Although they offer a relevant method of constraint classification, they do not make clear the relationship between information gathered and constraints derived, or between the nature of constraints used and the performance quality.

4.4.3 *Strategies*

Strategies are of interest because they can lead to better design. Therefore, one aspect of cognitive processing in problem solving, where much of the research has been based, is the way problem-solvers select paths to be searched. The procedures used are called heuristics, rules of thumb. Heuristics make use of information extracted from the problem statement and the states already explored in the problem space to identify promising search paths. The selectivity of heuristics can be derived from the structure of the task (Langley et al., 1987); this also explains the power of a heuristic. In the literature a distinction is made between hierarchically ordered *weak* methods (mostly general heuristics) and *strong* methods (task-specific heuristics, and algorithms), i.e. towards the bottom of the hierarchy more demand is made on information about the task domain. (Often the concepts of heuristics and strategy are used to explain the same rules.)

Examples of weak methods are (see Langley et al., 1987; Simon, 1966; Akin, 1986)):

* *Generate and test*. After one operator generates new instances, a second operator tests the new situation to determine if the goal is satisfied. As part of this method mental representations are accompanied by external representations like sketches and diagrams (Akin, 1986).
* *Hill climbing*. This method also uses a generate and test operator but in this case the evaluation of progress (the best solution so far) determines whether the solution is acceptable.
* *Means-end-analysis*. A test heuristic identifies specific differences between the current situation and the goal and examines only those operators which reduce the differences. This method is mainly known in solution guaranteed problem solving for which algorithms are present.
* *Satisficing heuristics*. In some domains problem solvers do not, or cannot, search for the best solution but for a solution that is 'good enough' by some criterion. This criterion is to some extent dependent on the aspiration level of the problem solver. For example in designing or chess playing the number of possible solutions is far too great, while efficient maximizing algorithms are not available.

A considerable amount of studies on strategies used in solving well-structured problems are conducted by comparing different levels of expertise. Expertise is not a matter of performing 'novice' procedures more efficiently. Experts show superior performance on recall tasks in which meaningful material is used, but are no better than novices when asked to recall the same material in a random order (e.g., Chase & Simon, 1973). Rather, experts are assumed to view problems in a qualitatively different manner and therefore have different representations of problems than novices (De Groot, 1965; Chi et al., 1981). An expert not only knows more than a novice, but there are qualitative differences in how experts and novices organize their knowledge about a domain and how they use that knowledge during problem solving. As experience increases, there tends to be a greater degree of intra-group agreement in relation to memory structure and organization. It has been suggested that the expert is able to perceive a more global picture and, therefore, is able to encode or chunk items into larger units than the novice.
However, the fact that people have acquired knowledge that is relevant to a particular situation provides no guarantee that access will occur. Knowledge must be activated when required. Access is facilitated when previous experiences provide a basis for inducing relevant schemata. For example access is facilitated by learning activities that help students experience problems and then experience the usefulness of information for solving those problems (Bransford et al., 1986).

In an overview of literature Elio & Scharf (1990) summarize the differences between novices and experts. Conclusions are derived not from the domain of designing but from other 'semantically rich' domains, where research on cognitive processes provides part of a theory. Although the kind of problems to be solved in these domains is often different from design problems, there is sufficient congruity between them to adopt their findings as a starting point:

Novices
- Use a 'working-backwards' approach: e.g. solving a physics problem by generating an equation which solves for the desired variable. If the selected variable contains an unknown, another equation is selected to solve for this variable, and so on.
- Tend to suggest solutions and equations soon after reading the problem statement.
- When spending more time analysing a problem qualitatively, they often either fail to generate a necessary inference or generate faulty inferences.
- Have sparse problem prototypes organized by superficial features from what is known in the problem situation.

Experts
- Use a 'working forwards' approach: from the known variables of the problem statement, generating equations (in physics problem) from which additional quantities become known.
- First engage in a kind of qualitative analysis. This qualitative analysis is marked by domain inferences that generate additional useful information about the problem situation which was not explicitly stated in the problem statement. It is defined as the 'knowledge-development' strategy, because it leads to an enriched representation of the problem situation clarifying the underlying principles involved and the relevant solution method.
- Domain inferences guide the retrieval of problem-solving knowledge and methods that are organized by abstract concepts and solution principles. A model of expertise is assumed to be: some kind of knowledge unit like a problem prototype or schema which guides the solution process. A problem solver first categorizes a problem through preliminary analysis of its features, activating a particular problem category. The declarative and procedural knowledge in this activated category then influences the problem representation constructed during solution.

4.4.4 *Strategies in design*

Within the domain of designing the results of studies on strategies can be summarized as follows:

Firstly, as opposed to the problem focused strategies of scientists, designers adopt a solution-focusing strategy for the resolution of ill-defined problems. Even when the problem is well-defined a designer seems to act as though there is some nebulousness surrounding the goals (Cross, 1990). Secondly, designers use conjectured solutions as a means of problem analysis. Related to this is the problem-solving strategy known as 'generate-and-test', mentioned in most studies on design and engineering design (Cross, 1990). The TOTE-unit (Test-Operate-Test-Exit), described by Akin (1986) as a simple control mechanism, is an example of this strategy.

In a overview of literature on mechanical design Stauffer & Ullman (1988) sum up 27 strategies of designers, which can be divided into four categories:
- The algorithmic versus heuristic nature of design. They conclude that there is no strategic plan in design. The procedures followed are of a general nature; designers only follow 'rules-of-thumb', dependent on the situation at hand.
- Parallel versus serial development of solutions. The conclusions on this topic contradict each other, which can possibly be attributed to the designer working in a group or individually.

- Technical versus behavioral nature of design. Most studies reviewed suggest that design is either technical or may include some independent behavioral aspects.
- The dependence versus independence of design or domain knowledge. The authors oppose the already mentioned systematic design theories in which the process is seen as independent of domain knowledge. The studies reviewed illustrate that domain knowledge is important in solving design problems.

Some of the findings presented here are, in the light of this study, viewed as typical for mechanical design. However, because in industrial design engineering behavioural and technical aspects are equally important, the assumption on the technical versus behavioral nature of design does not apply. In another publication the same authors present some weak methods, so-called 'local methods', used in their own studies into mechanical design (Stauffer & Ullman, 1991). The methods mentioned do not differ from those found in other studies both in design and other domains. The most frequently used method in mechanical engineering is means-end-analysis, but there is also generate-and-test, as well as generate-and-improve, a modification used in optimization procedures, and deductive reasoning.
In Lera's review study on architecture (1983) some other features of strategic behaviour are stressed. Design students, involved in a protocol analysis study of Simmonds (see Lera, 1983) differed considerably in their strategies used. However there was some agreement in one aspect of the design process; once an idea had been given concrete manifestation it remained in some form through to the final solution. Somewhat similar to this finding was the conclusion of Foz' study (in Lera, 1983) in which the subjects did not generate and test many alternative design proposals. The designer concentrated his efforts on something recognisably unfamiliar. Exploration of the problem evoked previously known solutions, which as precedents were used as guides for analysing or developing proposals in terms of programme requirements (Lera, 1983, p. 134).

Finally, a common strategy reported extensively throughout nearly all studies on solving design problems is that the process will be *decomposed in a subset of independent sub-problems* (Akin, 1986; Chan, 1990; Hamel, 1990; Simon, 1973; Thomas & Caroll, 1975; Ullman et al., 1988). Regarding this view ill-defined problems can be translated into well-defined sub-problems. The same assumption is held by Simon (see Simon, 1973; and Langley et al. 1987), who states that the mechanisms involved in solving ill-defined problems are not peculiar to that activity but can be subsumed as special cases of the general mechanisms of problem solving. In his judgement the component processes are not qualitatively distinct from the processes that have been observed in simpler problem-solving situations. He refers to the strategy of decomposing complex problems into sets of simpler problems and then tackling those. In the end, from the sub-solutions, an overall solution has to be composed.
However, it is seriously doubted here whether this strategy is applicable to the conceptual stage of industrial design.

4.4.5 *Representation by sketching*

Through both personal and 'public' objectives, in the conceptual stages of the design process, designers make extensive use of sketches and diagrams. These external representations

consist, as Larkin & Simon (1987) state, of both data structures and programs operating on them to make new inferences. Penultimately the act of drawing is intended to communicate between the designer and the manufacturer, but during designing drawing has the function of allowing communication between the designer and himself. Drawing can serve as the external memory of the designer. Moreover, as is stated by Foz (in Lera, 1983), visualisation facilitates the manipulation of ideas.

Within the exploratory stages of the design process there is a special variety of drawings which are categorised here as *study drawings (or - sketches)* (Goldschmidt, 1991; Herbert, 1988). The function of study drawings, which are mainly rough and abstract, is to conduct an internal dialogue. Sketches are in the opinion of the author, a reflection of cognitive processing, by which information can be reduced and kept under control. Consequently, this part of the account compels further analysis. Herbert (1988) points to some interesting properties of study drawings. Even a simple design brief generates so much raw data that it must be abstracted before it can be used. Larkin & Simon (1987) postulate an *attention management system* that determines what portion of the data structure is currently being attended to. Through this abstraction, part of the information may be lost at any level of the mental activity. Study drawings, thus, embody a set of these hidden structural relations. Herbert (1988):

> "So, the first study drawings for a design project are by no means as naive as their rough appearance suggests: their content reflects previously made irreversible decisions entailing losses of information about the reality of the problem." (Herbert, 1988, p. 29)

As the design work progresses the designs become richer in content. Study drawings provide the means to add information from the designer's cognitive experience. In Herbert's opinion, the losses of information are compensated for through the creation of new structures drawn from these experiences through mental images.

The question is whether the functions of drawing as touched upon here, will be manifest when observing a designer. And whether the designers increasing expertise, through which the drawing skill becomes more and more sophisticated, relates to the way they make use of drawing.

4.4.6 *Information in design*

Investigation into the role of knowledge in design is of course, focused on the processing of internal and external information. The richness of internal information is dependent on prior knowledge. If this is insufficient to solve the problem at hand, designers should seek additional information. In design education students often learn to gather information as soon as they're given the initial design brief. The information can be used to reduce the problem space by formulating specifications and requirements. Simmonds (in Lera, 1983) stresses the ability to assimilate new information into existing patterns and to adjust existing patterns to new information. However, in his study only a few subjects (design students) were able to make this latter adjustment.

The question is whether the designer is inclined to use external information. In a study by VanAndel & Christiaans (in press) 20 second-year students, involved in a formal design

project, were given extra information on some behavioral aspects of the user. Through the assessment of their design models by independent judges it was discovered that the way the information was presented influenced the assimilation of information. Moreover, a number of students gratuitously copied the solutions of examples presented in the extra information. However, in other studies the effect of information transfer is rather small. Hamel (1990) in his protocol study among architects, discovered that contrary to his expectation few participants asked for information at all. The information about use and users, unless given in the design brief, was retrieved entirely from their own knowledge of the domain. Powell (1987), coming to the same conclusion, refers to MacKinder & Marvin (1982) who recorded a strong reluctance on the part of the designer to consult written data. Powell puts forward several explanations for this finding. He states firstly that designers have learnt to become 'managers of uncertainty' and to be able to cope with lack of information. Their personal frame of reference is most important, because:

> "...in effect it constitutes the evolution of the designer's educational development." (Powell, 1987, p.194)

Secondly, there is insufficient time to even attempt to know about everything. He proposes a number of criteria to information developers. Designers will only use information if it focuses on their problem and if they have confidence in it. As to the presentational style, brevity, clarity, and the use of visual illustrations must be stressed. The content should help to relate new approaches and solutions to known ideas and contexts. The content should also be accessible: designerly appropriate, ready-made answers. However it's nonetheless debatable whether the use of external information is again a matter of expertise, in that experienced designers rely more and more on their own knowledge of the domain while inexperienced designers still need a lot of information from outside.
Explanation for designers behaviour can be facilitated through exploration of the way they process information. Therefore, in this study thinking-aloud protocol analysis is used to investigate the information-processing design activity. Although the appropriateness of the technique is still under debate, it is assumed that the overt verbal expression of the information used during the design process reveals a suitably accurate picture of the designer's activity.

4.4.7 *How to focus on domain knowledge in design?*

In order to understand what role domain knowledge plays in designing, in relation to the information gathered, the strategies used, and the way decisions are made regarding constraints, the designer must be observed whilst involved in a design task. In this situation the designer is in a position to use and ask for information, and to perform the design procedure he/she is used to, or has learnt.
Within the educational context design students could thus be observed whilst they are involved in a design project as part of their formal course. However, a number of disadvantages prevent an objective measurement of the process. Students not only work in groups and are tutored during design courses, but also do a considerable amount of work outside the design studio. Moreover, observation in a real situation is very time-consuming, especially where

a sample of individual students is involved in the study. Thus, designing a controlled laboratory experiment asks for an accurately simulated design task. Simulation means that the assignment is similar to assignments in formal design projects and that students can show their normal question-asking behaviour. Within the literature some studies using this kind of experimental design are known. A related study by Kuffner & Ullman (1990) describes the method used as 'question asking protocols'. During the experiment an examiner who was familiar with the design problem, was available as design information resource. They refer to Kato (1986), the first author who used this definition. However, in Kato's study the method refers to a situation in which subjects have to learn to use an interactive (computer) system with the help of their tutors but without any instruction manuals. The tutor can inform the participant extensively at his/her request, even concerning procedures. This approach must be altered in a simulated design situation. The experimenter should be reserved in supplying information, while the source of information should be in written form.
Another problem of the educational setting is related to the subjects level of expertise. By using students in the experiments, experts cannot be refered to; final year students, the highest level in this context, can only be defined as *intermediates*. However, they can be compared to *novices* within the domain, defined as students who only have little experience with designing. This definition of expertise will be expanded upon later.

4.5 *Other relevant factors in problem solving*

It is expected that the way designers go through the design process and the kind of knowledge they use, will be important determinants with regard to the output of the process. These aspects were mentioned previously. But in general, the ability or skill in problem solving will depend on at least two other factors: the individual capabilities of the problem solver, and their level of expertise. Both factors can be defined in different ways. However, because of the educational setting in which the study is done, a definition of capabilities is established in terms of schooling grades for design courses, and a definition of expertise in terms of seniority. Hence, in conducting experiments on solving design problems both factors must be controlled.

4.6 *Relationship with performance quality*

One of the aims of this research project, consistent throughout all chapters, was to investigate the relationship between the design process, conceived as an information-processing activity, and the result of the design process itself, measured by the creativity of the design solution. As was stated before, a product definition of creativity is adopted using the consensual assessment technique of Amabile (1983) to judge the design solutions. In chapter 2 the method itself and the reliability of the method are discussed. Based on the positive results of the aforementioned studies, it was assumed that the creativity criterion was to be very useful as regards this final study.

4.7 *Protocol study*

4.7.1 *Method*

Subjects

Subjects included 20 students again from the School of Industrial Design Engineering, Delft University of Technology. They were selected according to two criteria. First, in order to control for the level of expertise, 10 2nd-year students and 10 final-year students were selected. The second control variable, the individual capabilities of students, was defined in terms of high and low grades for the formal design courses (see below). Each subject performed the design task individually.

Design task

The assignment was to create one or more concepts for a new 'litter-disposal-system' for a contemporary Dutch railway carriage (SM90). As far as industrial design engineering is concerned, this problem is typical in that it calls for the integration of a number of aspects, such as ergonomics, construction, engineering, formgiving and aesthetics, and business aspects. Moreover, the system can function in one simple design. The design brief outlined the problem, introduced the stake-holders and defined the subjects' position:

> "The client
> Lemmens Ltd. is a manufacturer of plastic trays and buckets. The factory has 40 employees at present, spread over 10 injection-moulding machines, an assembling division, and a small instruments division. Most products are injection-moulded; small amounts of special runs are also produced by vacuum forming, or roto-moulding (contracted to TenCate Roto-moulding).
> Lemmens manufactures its own small product-range, aiming at the institutional market. Furthermore, it is supplier to, for example, Curver PC in Oosterhout. The intention of Lemmens is to extend its own product-range in the next few years, and to decrease the supply.
>
> The brief
> The Dutch railway company (NS) is preparing a number of new trains for the nineties, one of these is the new local train SM90. This is a completely new design, in which the passenger capacity is increased by placing 5 seats (2+3) in a row. Because of the growing number of people travelling a new refuse system (waste bin + cleaning tool) for the passengers' compartment is to be considered.
> In answer to this brief the current supplier of the refuse system made a new proposal which after consideration was not accepted by NS. Next, NS conducted a survey among passengers and cleaners as to the functioning of the current refuse system; moreover, they investigated the kind of waste in the bins.
> On account of this study NS decided to invite Lemmens Ltd., among others, to make concepts for a new design. The director of Lemmens Ltd., mr. Kouwenhoven, and the project manager of the NS, mr VanDalen, have already discussed the situation.
> Lemmens Ltd. takes the view that supplying such a product gives an opportunity to increase its profile within the market.
> You are engaged as free lance designer to design several concepts. Tomorrow you have a meeting

in which the following concepts will be discussed:
- A basic solution
- Main solutions for realisation
- Idea behind the design
- Drawings
- Costs estimation"

Information system

A special condition in the experiment was the way in which information was provided to the subjects. All the information it was thought they may require during the design process was put on cards, on each card one specific topic was presented. Topics could also entail an interview with the client, or a survey study among train passengers. The lay-out and content of the cards do satisfy the aforementioned criteria by Powell (1987). The list of topics on cards, as well as some examples of cards, are included in appendix Va and b. If a subject wanted to know something, he or she asked the experimenter, who was sitting at the same table. The experimenter would then look for the appropriate card relating to the question posed, and hand it to them. This was done to ensure a quick but natural flow of information. The information on the cards was presented as coming from different natural sources: from study books, from shops, catalogues and from the different stakeholders presented in the design brief. As a result the information contained natural amounts of vagueness and inconsistency. The number and 'kinds' of cards subjects asked for was noted. If the information was not available on cards, or if the question related to a detail of the card, the experimenter gave the answer orally. Because the experimenter's background was not in design, he was connected via headphones to a second experimenter who was familiar with the task. Experimenter 2 was sitting in a adjacent room where he could see and hear the subject (see figure 4.1).

Procedure

Subjects were requested to think aloud as they were solving the design problem. The design session was preceded by a short training exercise, to help them become accustomed to thinking-aloud. The instructions read out by the experimenter, were:

> "What is a designer doing when performing a design task? What is he/she thinking about? What kind of decisions are made? What information is needed to solve (sub-)problems? These are the questions in our study. You are a beginner in design and as such can give us an understanding of the designing process. Presently you will be offered a design task, similar to the ones you're familiar with from the design course. We want to know how you design. Therefore, we ask your permission to videotape this session.
> Because we want to understand what you are thinking during the task, I also ask you to think aloud. Most important is that you continuously speak what you think, from the very beginning of the task. Act as if you are talking with yourself, but in such a way that I can hear you.
> I can imagine that it feels odd. In order to get used to thinking aloud, I will give you a small problem which has nothing to do with the design task. Try to solve this problem while thinking aloud. Do the same while reading the instructions: as if you're talking with yourself."

The pre-task used was the DONALD + GERALD = ROBERT puzzle, extensively used and analysed by Newell and Simon (1972). While solving this problem, the subjects were continuously encouraged to think aloud. After 10 minutes subjects were asked to stop the session. Next, the following instructions, preceding the design brief, were read out by the experimenter:

> "Now I offer you the design brief. As I said, it's similar to a problem you'd be challenged with on the design course. Only time is limited now: just 2½ hours.
> In a normal design project a substantial part of the time would be spent gathering information, reviewing the relevant present product domain etc. In order to save time we've developed a solution for the information accessing problem.
> We've put all the information that you should need, in a normal situation, in a card-tray. Information on the design task, the client, the user, and on all kinds of visualisations, but also details from text-books and notes from your department: information on engineering, ergonomics, form theory and styling, business aspects etc. This information is at your disposal, provided that you ask for it. If you do request it then it's recovered by me, which sometimes takes a little time, but meanwhile you may continue working.
> Again, don't be reserved in asking for information, because it may contribute to an improved result. Moreover, we are interested in what information a designer uses. So, ask for everything you think you need, or look for in a normal situation.
> In short, work like you are used to, but continue to verbalise throughout whether you are reading information, sketching or thinking. Otherwise we don't know what is going on in your mind. Occasionally, I will remind you to keep thinking aloud.
> My role is to act as a source of information, and a reminder for you to keep thinking aloud. I don't want to influence you at all. Thus, don't react to what I am doing.
> I won't persistently remind you of the time; after 2½ hours I will ask you to stop working. There is a clock in this room. Do not mind me. If you want to take a break, do it. You can leave the room for a short period."

The design brief was then handed over to the subject. The time allotted to them was 2½ hours. During this period subjects were encouraged to think aloud if intervals of silence lasted more than 30 seconds. Remarks like "What are you thinking now", or "I'd like to hear what you are thinking" were used.
After the design session, there was a short interview to determine the motivation and attitude of the subject towards the test situation and his/her own design.

The verbal reports and sketches were recorded by two video cameras (see figure 4.1).

4.7.2 *Creativity assessment*

In order to assess each of the 20 designs in a consistent manner, they were all sketched in a similar style. Each of the cardboard models was photographed and recorded on slides. The design solutions generated are presented later in the text.
Six design teachers from the School of Industrial Design Engineering, involved at that time in a teacher training course, were asked to rate all 20 designs individually on six attributes: creativity, technical quality, attractiveness, utility, economic value, and an overall judgement.

After viewing the slides subjects had to read the instructions concerning the first attribute. These instructions were identical to that used in the creativity studies described in chapter 2. Then, all designs were shown again and assessed, whereupon the next assessment attribute was presented showing once more the 20 designs, etc. After each attribute the slides were arranged in a different random order.

4.7.3 *Measurement of expertise and design ability*

The role of knowledge in design is studied here by observing the development of knowledge acquisition in design students. In order to control for prior knowledge, both the level of expertise and the design capacities of the students in our sample are measured. Two separate levels of expertise are defined: novices (2nd year students), and intermediates (final year students). This distinction was derived from Allwood (1986) who, refering to Scheiderman (1976), uses four levels of expertise: *Naive* subjects who have not attended any course, *novices* who are currently enrolled in, or have just completed their first course, *intermediates* who have just completed their second or third course, and *advanced* subjects, also called *experts*, who are graduates or department members. In this study the intermediates will include subjects who are almost qualified, while novices have completed their first year, and are now enroled in the first design course of the second year.

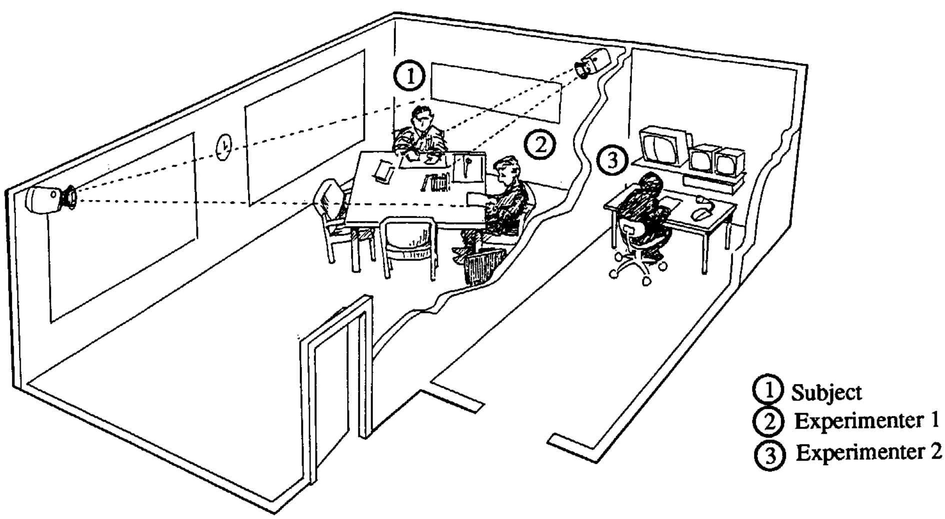

Figure 4.1 Experimenter room

Design capabilities were assumed to be shown by the grade point average in designing attained throughout the course. Two levels of ability were used, high and low. The design ability was defined high if, on a ten-point scale in which 5 is a fail and 6 is a pass, the grade point average for only the design courses was ≥ 7, and low if the average was below 7.

Within the sample, five students in each group of novices and intermediates had high grades, while the other five of both groups had low average grades.

4.7.4 *Analysis of protocol data*

Protocols are encoded in different ways, depending on the aim of the analysis. Moreover, the analysis was performed by two independent data encoders.
Firstly, in order to investigate the relationship between the subjects general strategy, and the creativity of their solution, a rough classification of activities performed by a subject was made. This classification was based on the time spent by each subject, on any of the following activities: reading the design brief, gathering and reading information, sketching, and reflecting on the problem at hand.
Secondly, for an understanding of what was going on during the design process the protocols of all 20 subjects were analysed on the topics mentioned previously: decision making, strategies, constraints, information need, and presentation by sketching. In a second analysis 6 students were selected from the total sample in order to explore, in more detail, the relationship between the creativity of the product and the preceding process. Three subjects were taken from the sample of 2nd-year students and three subjects from the final-year students. A second selection was made on the basis of the product creativity rating: 3 subjects with the highest rating were chosen as it was assumed they would be able to contribute most to the understanding of the problem-solving process. The other three were selected on the basis of whether their particular design process would serve as a model for the processes observed within the sample of 20 subjects. In encoding the protocol data of the 6 students a classification system was used which was an adaptation of the classification used by McGinnis and Ullman (1990) into product elements and constraints. As they state, every sentence a subject utters, and every sketch, is assumed to be a stable entity, defined as *product element*; as soon as an element is altered or qualified, it is defined as *constraint*.

In this study these two categories are completed with *strategies* and *ideas*, together with product elements and constraints defined as follows:
- Strategies; overt statements as to the strategy used, including comments on the planning of the task.
- Product elements; all aspects which are related to the problem at hand, and to which the designer attends. These can be a product or a system, their attributes, or a context such as location or user behaviour.
- Constraints; requirements, specifications, and value statements connected in verbal or numerical form to product elements or attributes. Design 'requirements' act as constraints, and are the restricted prescriptions with which the design must meet. According to McGinnis & Ullman (1990) constraints are further detailed in *given*, *derived* and *introduced* constraints. This distinction is explained previously.
- Ideas; solutions for the design problem, or part of the problem, generated during the process.

In appendix VII the six protocols are presented which have been encoded according to these four categories.

4.7.5 *Results*

Creativity

Judges assessed the output of the 20 design solutions on six attributes: creativity, technical quality, attractiveness, usefulness, economic value, and overall value. In table 4.2 the average correlations among the judges are presented. In order to compare the results with the previous studies on creativity, α-coefficients for every attribute are also calculated. Regarding creativity the intercorrelation between judges is high, in contrast with the results of the other attributes. The same holds for the inter-rater reliability, the coefficient α. These findings confirm the results of previous studies. The average score can be used reliably as a measure for creativity. In chapter 2 the creativity concept's validity was discussed.
In appendix VI correlations between the average scores of the attributes are presented. Because in this study the relationship between the design process and these other 'unreliable' attributes is not of interest, they will not be discussed further.

Table 4.2 Average intercorrelations among 6 judges, and α-coefficients

Attribute	Average intercorrel.	coefficient α
Creativity	.67	.89
Attractiveness	.32	.71
Technical quality	.23	.60
Usability	.35	.73
Economic value	.26	.68
Overall value	.34	.75

Influence of expertise and design capacities

The students level of expertise and design capabilities in the sample were expected to influence performance quality. Expertise was defined by distinguishing two levels: novices (2nd year students), and intermediates (final year students). Design capabilities were assumed to be shown by coursework grade point averages in designing. Performance quality was defined by the average product creativity rating (PCR).

In table 4.3 the average creativity ratings are presented in relation to both expertise and design ability (average design grade). The PCR per subject is illustrated in table 4.4.
The results show a small, but not significant, effect of expertise in favour of the intermediates. The effect of design grades is greater, but in the opposite direction. As far as creativity is concerned higher grades in the formal design education system apparently do not guarantee better performance in a test situation.

Table 4.3 Average creativity ratings for four groups of subjects. Groups are classified according to level of expertise and average design grade

Average PCR	Low grades	High grades	Total aver.grade
Novices	5.9	4.6	*5.3*
Intermediates	6.3	5.6	*5.9*
Total average expertise	*6.1*	*5.1*	

Protocol analysis

The findings of the protocol analysis are now described according to the previously defined relevant design aspects: decision making, strategies used, constraints, and information retrieval. Because of many inter-related factors a strict separation of the aspects is impossible. The rich data from the protocols produce mainly qualitative results; if possible quantitative data are added. In the analysis the relationship between expertise and performance quality was taken into consideration.

Decision making

Although a decision underlies every minor change of state, only general decisions are taken into account. One of the most influential decisions taken seems that concerned with problem definition. This decision has obviously important consequences for the ideas generated, and the creativity of the end result. The data from subjects show, that there are essentially two approaches. The first one within this particular design task is to limit the problem to only a problem of redesigning the refuse system, the waste bin, without any consideration for other systems. This can be defined as a *convergent* way of thinking. The second approach, a *divergent* one, is to expand the possible answers to the problem in order to generate a wide range of solutions. Most subjects (14) have a convergent approach. This manifests itself in the kind of information asked for, and in the requirements formulated from the beginning. However, it is questionable whether this choice of approach is taken consciously. Moreover, the design brief probably evokes this approach.
Are differences in decision making related to the level of expertise?
Nearly all novices (8 out of 10) reduced the problem to a redesign of the refuse bin. Partly, this is a consequence of another novices characteristic: they in general treat the design problem as if it were a normal second-year design course assignment. Meaning, they consider the problem on their own simplistic level, without considering its real complexity. They don't think in systems or functions, just purely in visible forms and handling. This approach has a major effect on all activities within the design process. In general, their approach can be defined as *solution-oriented*, i.e. they are focused on solving the problem without exploring deeply the problem. There were two subjects who differed from their sample; one of them

failed (s. 19) in his attempt to explore the problem by asking a considerable amount of information, and the other (s. 17) was able to generate a concept with a high creativity rating. Four intermediates used a divergent approach in that they initially do not restrict the problem to a certain solution. They talked about "changing the system" and "what is wrong with the current system", meaning that they considered the whole system including ways of throwing away rubbish, and the cleaning procedure. The other six intermediates, like most novices, reduced the problem to simply a redesign. Some of them got stuck in the concept generation phase, and decided to adjust their goals by lowering their aspirations. As a consequence they reduced the problem-solving activity to minor problems, taking the current bin system as a model. However, it is clear that this decision is based upon different reasons than those of the novices. Whether they choose to design a new system or again another refuse bin, nearly all intermediates tend to employ a more *problem-oriented* approach. This is manifest in decisions relating to the time spent analysing the problem and gathering information (see table 4.6).
Looking at other differences, some subjects postponed decision making as if they were almost frightened that they would solve the wrong problem. The way some subjects, 2 novices and 3 intermediates, searched for information gives the impression that if knowledge is not yet structured according to an internal representation of the problem and decisons taken are not goal-directed, new information will be lost because it is never compiled. These same subjects also attempted to get the experimenter to take decisions for them.

Relationship with creativity. The aspects mentioned so far seem to influence the quality of the result. Firstly, adopting a divergent approach increases the probability of a more creative product. These subjects generate more system solutions, which enable them to select one of these. For three of the subjects with the highest creativity ratings this conlusion is illustrated later. Secondly, subjects who stick to the problem orientation, postponing any decision regarding the solution direction, and who expect to find a problem structure within the information asked for, created products with a low creativity rating. Thirdly, the aspiration level throughout the process seems to play a role; although all subjects were obviously motivated to perform the design task, some of them were frustrated when, after one hour working, no idea had crossed their mind. Consequently, they lowered their aspiration level.

In order to analyse decisions on a more detailed level, the role of constraints is now investigated.

Constraints

The way in which designers reason from function to form can be illustrated by observing the process of transforming knowledge of the problem into constraints.
Immediately after reading the design brief all subjects began writing specifications and requirements, as given in the brief. These are forms of constraint concerned with the product and with context variables like the interior of the train, and some ergonomic data. Then, most subjects requested supplementary information, of the form mentioned in the brief. In this information new constraints were given or derived by students. Other subjects, mainly novices, asked for very little information, but instead introduced constraints from their own

knowledge activated. However those who hoped to derive solutions from the list of requirements were disappointed.

A considerable number of subjects seemingly failed to realise that designing is not a mode of deductive or inductive reasoning. The term 'reasoning' seems scarcely appropriate when looking at what precedes a solution; indeed, some solutions were derived indirectly from the constraints given in the information. For example, information cards highlighted the fact that the refuse bin was too small, and that 40% of the rubbish put in was newspaper. The idea of a separate newspaper-bin was then explored by five subjects (two of them forgot the idea later). Other subjects, who only enlarged the undersized bin, did create a new design, but the concept was far from creative. However, in the development of solutions this simple mode of reasoning is rarely met. Reasoning from requirements, without an understanding of one's own plans, seems to block creative solutions. This was evident in those subjects who continued asking for information and adding new constraints, without a real understanding of the problem, or solution direction. They got stuck with an enormous programme of requirements, and consequently a plethora of restrictions with no real problem to work on in a positive sense. They thereby managed to block themselves psychologically, and were unable to think of any new concepts. After reaching this dead end they tended to do one of two things: (a) use their programme of requirements to evaluate the current design, and propose some alterations, or (b) take a comparable product, e.g. a letter box, evaluate it, and make that into a waste bin. It was clear in the experiment that subjects behaved strictly as they'd been taught in their design education; i.e. following a rather stringent sequence of gathering information, formulating a program of requirements, and generating ideas. In this study such method did not work very well; on the other hand, the education method used may possibly generate more successful solutions, if more time is available to perform the design task.

Although it is difficult to demonstrate a relationship between specific product elements and constraints on the one hand and on the other the kind of solutions generated, there was one aspect which is often connected to new ideas: the *location* of the refuse system in the train. As soon as other locations were established, virgin ideas were very forthcoming.

Some more differences are related to expertise.

Novices tended to introduce some of the constraints from their own knowledge. But, since most of them only solved the problem of the refuse bin, and not the whole system, the number of specifications and requirements was restricted. As to the determination of priorities in constraints, the simple problem treatment by some novices led to bias, overcompensating the requirements that posed the greatest difficulties.

Intermediates again differed amongst each other in the way constraints were employed during the process. As mentioned previously, some subjects became completely baffled through their aimless gathering of new constraints, unable to determine priorities. Others tended to draw up a list of 'things to think of', containing just four or five items, and then started designing. The program of requirements was only adopted when their ideas had to be evaluated. These students were better able to form conceptual structures by way of abstraction of the information given. The raw data available to the designers are so abundant that a certain amount of abstraction is imperative. It seems, novices have not yet developed this ability. The fact that most intermediates do not demonstrate this skill is possibly due to insufficient education.

Strategy

Decision making is of course closely related to the strategies used by subjects. In general, when the protocol data are analysed in detail it could be observed that the twenty subjects all use different strategies. However, a number of similarities can also be observed which are related to expertise level. The overall strategy of novices and intermediate designers differs in some respects.

One of the strategies used by some novices and most intermediates is what could be described as 'means-end-analysis'. Through this strategy the subjects identify specific differences between the current situation and the goal, and examine only those operators that reduce the differences. Subjects who worked this way, began by asking themselves what was wrong with the existing system; the next step was then to ask for relevant information. For some other subjects it was not until their idea generation ceased that they started evaluating the existing system.

A second strategy observed in this study was the 'generate-and-test' strategy; subjects used conjectured solutions as a means of problem-analysis. This strategy was adopted by those novices (in the majority) who decomposed the problem into sub-problems. By way of sketching they generated and tested alternatives for each sub-problem; this will be refered to later. Intermediates also showed this strategy, but with a slightly different goal, because they used it to test a solution for the whole problem, not just sub-problems.

Other subjects generated very few solutions for the problem, and once a solution had been generated most of them tried to realize it immediately.

Because the knowledge base of novices is rather weak, we might expect that they ask for a lot of information. However, the protocols show that they tend to generate much information themselves. On the whole, they solve a simple problem; that is to say, they ignore a lot of the complications in the assignment. As was stated before, the abstraction of the design problem, which reveals how the subjects select and organise the data, is done by 2nd-year students on their own level of competence. They don't even realize that they lack certain information. As a consequence novice designers treat the problem on a much simpler level than intermediates.

When compared to novice problem-solvers in other domains, such as physics, novice designers demonstrate similar strategies. Firstly, most of the 2nd-year subjects decided soon after reading the design brief to simplify the problem to a redesign of the waste bin. Allwood (1986) poses a similar notion; novices tend to devote less time to developing their understanding of the problem. Instead, they try to solve a problem which they can comprehend. Secondly, novice designers engage a 'working-backwards' approach which is characterized by then solving successive parts of the design problem without really considering the overall design. For example, after the decision to redesign the bin, the novice starts thinking about the problem of fixing the bin to the train wall. This thinking is generally coupled with ideas generated through sketching. Next, the problem of the lid is tackled in the same way, and so on. Two subjects had a different strategy, they asked for a considerable amount of information, but both failed to generate satisfactory solutions for the design

problem. Time, it seemed was too short to build up a new cognitive structure based on the information gained.
The intermediates demonstrated different strategies. As already discussed generally this group adopted a more problem-oriented approach. They were much more deeply engaged in a kind of qualitative analysis, especially during the first half of the process. One of the most striking results, when the protocols of intermediate designers were analysed, was that subjects did not split the problem up into independent sub-problems, but tried to solve it as a whole. This finding contradicts all studies concerning design in architecture and mechanical engineering, as is refered to previously. Although in prescriptive models of both domains and of industrial design engineering problem decomposing is strongly adviced, it is apparently not the actual problem solving strategy of more experienced designers.

Table 4.4 Data per subject: Level of expertise (2nd versus 5th (=final) year), average design grades, Product creativity rating (PCR), amount of time spent on four activities at two periods of the process

				0:00-0:30 Amount of time spent to:				0:31-1:00 Amount of time spent to:			
Subj	2nd/ 5th	Design grade	PCR	Read brief	Infor- mation	Sketch	Reflect	Read brief	Infor- mation	Sketch	Reflect
1	5th	h	5.7	5.5	16.5	1.5	6.5	4.0	20.5	0.5	5.0
11	5th	h	5.5	5.5	10.5	1.0	13.5	0.5	6.5	3.0	13.0*
13	5th	h	6.7	4.0	10.0	1.5	14.5	0.0	2.5	5.5	22.0
16	5th	h	5.7	4.0	14.0	2.5	9.5	0.0	9.0	4.0	17.0
19	5th	h	4.2	4.0	14.0	0.0	12.0	1.0	8.0	1.0	20.0
3	2nd	h	3.7	1.5	2.5	9.5	16.5	0.5	4.0	8.0	17.5
4	2nd	h	5.7	1.5	8.0	2.0	18.5	0.5	1.0	7.0	21.5
5	2nd	h	4.5	3.0	12.5	0.0	14.5	0.5	12.0	3.0	14.5
7	2nd	h	5.3	5.0	15.0	1.5	8.5	1.5	10.5	5.0	13.0
18	2nd	h	4.0	9.0	19.5	0.0	1.5	0.5	13.5	3.0	13.0
6	5th	l	8.5	5.5	8.5	2.0	14.0	1.5	7.0	0.0	21.5
8	5th	l	6.8	3.0	9.5	7.0	10.5	0.0	3.5	9.5	17.0
9	5th	l	6.7	4.0	8.5	4.0	13.5	0.0	3.0	5.5	21.5
12	5th	l	5.7	4.5	18.0	0.0	7.5	0.0	20.0	3.0	7.0
20	5th	l	3.7	4.0	15.0	0.0	11.0	0.0	7.0	6.5	16.5
2	2nd	l	3.3	2.5	15.5	2.5	9.5	0.5	4.5	10.0	15.0
10	2nd	l	4.5	3.0	14.0	6.0	7.0	0.0	1.0	16.0	13.0
14	2nd	l	5.8	4.5	9.0	0.0	16.5	0.0	3.0	6.0	21.0
15	2nd	l	7.5	2.0	4.0	0.0	24.0	0.0	1.0	17.5	11.5
17	2nd	l	8.5	2.5	8.5	2.5	16.5	0.5	7.5	6.5	15.5

* Subject 11 took a 7 minute break

There are differences between intermediates, which also seems to be related to the creativity of the design. One group, mentioned previously, began by gathering aimlessly a very large amount of information. They seemingly wanted to take into account all the constraints given, but got stuck because of inconsistencies in the information provided. Consequently they lacked a clear, definite design goal and hence delayed decision making.

The second group asked for less information, processed it instantly, and gave the impression of consciously creating an overall image of the problem. They looked for and made priorities early on in the process. They also tended to reflect more on their design process, and to take time to lean backwards and think about the problem structure. The resulting designs were more imaginative than those of the first group.

Is there a relationship between the strategy used and the *creativity of the product*? In order to investigate this, classification of each students protocol was undertaken - four categories of activities performed during the first hour of the experiment were formed: reading the design brief, asking for and reading information, sketching, and reflecting on problem and solution. For analysis the first hour of each protocol was preferred because within this period the strategies used seemed to influence most the activities which followed.
In table 4.4, which is split into 2 half hour segments, the time spent on these four activities is presented.

Correlations between the time, spent during the first and second 30 minutes of the process, and creativity are presented in table 4.5. The range of PCR scores is mostly influenced by students with low design grades, i.e. the variance of PCR within groups with low grades is highest (4.8 and 5.2 for low-grades, and 2.5 and 2.8 for high-grades). Of course, the periods spent on these activities are mutually dependent, i.e. the more time spent asking and reading information will mean less spent on other activities. Nevertheless, the results at least suggest reflecting on the problem during the first phase of the process has a positive effect on the creativity of the result. In the second half hour this effect disappears. Confirmation of this finding can be obtained by analysing the design process of subjects with the highest creativity ratings. In the next section this analysis will be performed.

Table 4.5 Correlation between creativity and time spent on 4 activities during the first hour

Correlation with Creativity	Reading design brief	Asking/reading information	Sketching	Reflecting
Time: 0:00-0:30	-.06	-.45*	-.04	.44*
Time: 0:31-1:00	.03	-.14	-.00	.17

* Significant at $p < .05$

Information processing

The different search strategies in relation to the amount of information requested have already been mentioned. A more detailed view is presented here.
Firstly, looking at the time subjects spent gathering and reading information, novices and intermediates differ, on the average, significantly. After 30 minutes there was a characteristic drop for both groups in asking for information (see table 4.6).

Secondly, table 4.7 shows how many subjects (novices and intermediates) requested information cards.
This analysis was done again for only the first hour of the process, as this was when most of the information was sought.
On average, intermediates asked for more information on aspects of both the product (the refuse system), and the context in which the system had to function. The information presented on certain cards, and insinuated toward in the brief, was essential for generating adequate design solutions. This is illustrated in table 4.7. In spite of these hints part of this information, for instance the simulated survey study on opinions of passengers and cleaners (card S2), was ignored by at least 4 novice designers.

Table 4.6 Time spent asking and reading information

	Time spent gathering information			
	2nd-year		final-year	
Time span	$\bar{x}$	*sd*	$\bar{x}$	*sd*
1-30 minutes	10.9	*5.4*	12.5	*3.6*
31-60 minutes	5.8	*4.8*	8.7	*6.5*

There were also a number of questions about product details and context variables, which were not included on cards, but were answered by the experimenter. These were again posed in the same proportion: 17 by novices, and 34 by intermediates.

Questions on 'production methods', only asked for by novices, concerned a technique unknown to them but mentioned in the brief, i.e. 'roto-moulding'. This was one of the few instances where novices showed a lack of basic knowledge. Intermediates were already familiar with this technique.

Sequence of information

In general, after reading the brief nearly all subjects started with problem definition through exploration of the situation; they asked for information concerning the interior of the new train and the current refuse bin design. If these topics were not sought, it meant that subjects had to try and retrieve them from memory. During the period of problem definition subjects alternated between these two specification areas, irrespective of the kind of definition they adopted. As stated earlier, the location of the bin was often a source for idea generation. Questions on ergonomics were mostly concerned with anthropometric details regarding the distance between passenger legs and the bin. Information on such topics as construction, materials, and costs was only requested in the second part of the process, after the idea generation phase.

Assimilation of information

In contrast to data from other studies in design (Powell, 1987; Hamel, 1990), in this experiment there was no reluctance on the part of the student designer to consult written data. This may have been due to the background of the subjects, i.e. students who were still enroled in design education. Although on the other hand, the data show that, in general, the more experienced a subject was, the more he/she tried to rely on external information. However, the question is whether the subject was able, within the time available, to assimilate the new information, and to break through existing patterns of thinking.

Table 4.7 Information asked for during problem solving

Code	Information cards	Hinted at in brief	2nd-year	Final-year
	Situation aspects			
S1	Requirements of Dutch Railway		3	5
S2	Opinions of:	x		
	* passengers		6	10
	* cleaners		5	10
	Inquiry toward waste in bin		6	10
S3	Stakeholders	x		
	* manufacturer		1	4
	* Dutch Railway		1	3
S4	Railway carriage			
	* measurement of existing interior		6	10
	* construction of wall		1	3
	* interior sketches of new carriage (SM90)		2	3
	* general data SM90		9	10
S5	Passenger anthropometric data		4	3
S6	Vandalism		-	3
	Product elements			
P1	Current bin			
	* exploded view		4	6
	* technical drawings		8	8
P2	Redesign bin	x	3	6
P3	Examples of litter-disposal-systems		3	6
P4	Cleaning system			
	* emptier	x	8	6
	* cleaning procedure		5	5
	Production	x	5	-
	Materials	x	1	3
	Cost		4	1

In relation to the role of constraints, conclusions have already been drawn that suggest the quality of the final solution depends on whether the subject is able to grasp the problem

firmly. If a problem definition was postponed then it became difficult for the subject to assimilate new information to existing patterns. If on the other hand he/she had a real understanding of the problem, then the information was gathered according to a plan. In this case, the subject took time to reflect on what he was doing, to weigh information, and to process it by linking it to or changing existing patterns. However, very few subjects showed this ability. This area is returned to later in the text where six 'cases' (i.e. six students protocols) are treated.

Sketching

Sketches and drawings are assumed to be an important means of problem exploration and solutions generation. They are used as 'aids to thinking'. In the experiment here, by offering them all the necessary tools, subjects were encouraged to sketch and draw.
The data show that there are individual differences in the ability to sketch. This ability was dependent on both individual talent, and on experience. Both factors played a role in the way and the frequency these aids were used. On the other hand, if creativity is looked at, it can be concluded it was not affected by a subjects ability to sketch; some subjects, who were not motivated to sketch, and only started sketching after they had generated a number of solutions, produced very creative solutions. The idea generation in this case was performed through mental activity which was verbalized.
How does experience affect ability and consequently what is the difference between novices and intermediates?
Most novices begin sketching early on in the process; it seems their way of problem familiarization. As mentioned previously, the use of sketching reflects their overall strategy, i.e. a 'working-backwards approach'. They start with a sub-problem (usually related to the bin only), and by sketching they generate alternative solutions for that sub-problem. By and by they encountered more problems, and solved these 'on the way'. This strategy it seems is characterized by iterations, is not very controlled, and may lead to inefficient solutions. They did evaluate their design, but only implicitly, and were more concerned with inconsistencies between their sub-solutions, than measuring absolute or relative performance of the proposal they were working on. Presumably, the way novices use sketching also reflects the educational approach of the school of industrial design. In the first-year design course at Delft, accompanying the prior knowledge of novices, the use of sketching in the conceptual phase is reinforced by a extensive course in 'hand-drawing'.
On the other hand six intermediates it seems have 'unlearned' the use of sketching as an aid to explore problem and solution early on in the process. The analytical way they approached the problem is described previously. This approach lead to postponement of sketching. In contrast to novices, who began with a solution-oriented approach by tackling sub-problems, intermediates started by exploring the context of the problem. They all begin sketching the interior of the train with the location of the seats.
As to the presentation drawings at the end of the task intermediates, logically, show a more sophisticated drawing skills.

4.7.6 *Protocols of six students*

From the sample of 20 subjects the protocols of 6 are treated here in order to illustrate the findings presented just above. These findings are concerned with characteristics of the design process in relation to the creativity of the design solution. The selection of six subjects was based on the following considerations. Firstly, in view of the main objective of this study, i.e. an understanding of the relationship between information processing in design and creativity of the result, subjects whose products attained the highest creativity ratings would be analysed first. Secondly, from the overall analysis of all 20 subjects it was obvious that the level of expertise was an important factor which influenced the nature of designing and which hence should be included. Thirdly, in order to illustrate the typical strategies used by subjects the selection should consist of subjects who were 'prototypical' for the rest of the sample.
Three subjects with the highest product creativity rating (PCR) were taken from the sample, two novices and one intermediate (numbers 6, 15 and 17 in table 4.4). Three other subjects were selected, one novice and two intermediates, who used strategies which to some extent served as a model for other subjects (numbers 1, 10 and 12 in table 4.4).
The products designed by these six students are presented in figure 4.2.
Each subject will be described, as a separate case, with regard to the topics used before: decision-making, strategy, constraints, information-processing, and sketching. Only the first hour of each protocol is reported for the reasons illustrated earlier. The sequence in which the subjects are presented is the same as the aforementioned: the three high PCR students and next the others. The number designated to each subject corresponds to subject numbers in table 4.4.

In appendix VII one-hour-records of the six protocols are presented.

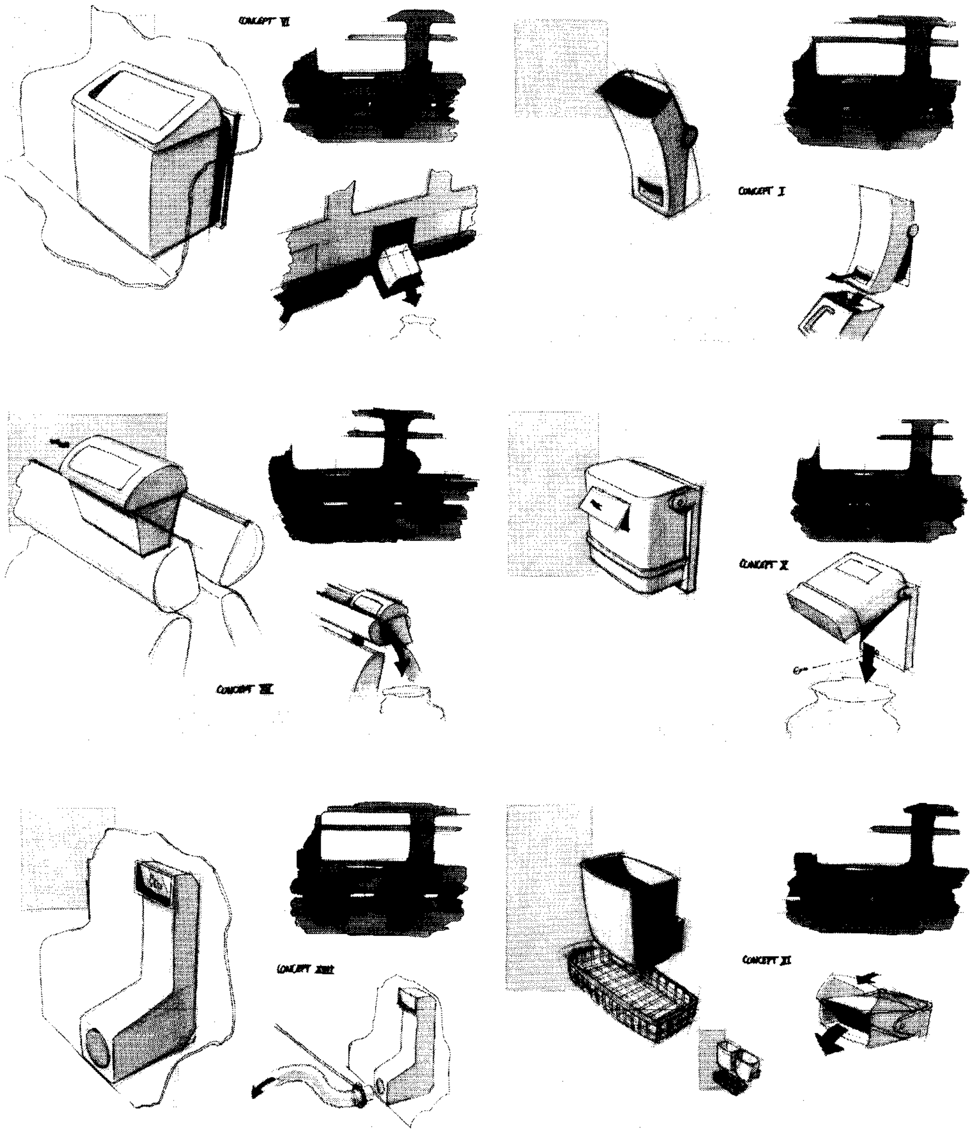

Figure 4.2 **Drawings of the design resultant, a train refuse system**

Subject 6

Intermediate
Creativity rating = 8.5
Average design grade < 7
The design solution is presented in figure 4.2a.

Subject 6 is explicit about his *strategy*, as he spontaneously states 38 minutes into the experiment:

> "I learnt to gather information endlessly, approaching everything methodically. However, the longer you postpone your ideas, the more you will be blocked. So I choose the following strategy; generate ideas in an early phase, and record ideas as soon as possible for two reasons; in the first place you create more room for new information, and in the second you avoid forgetting ideas."

He also talks explicitly about the refuse 'system', indicating that he considers the problem from a wide perspective.
From the beginning he reflects on the problem at hand. Figure 4.3 shows the alternation between reflecting and information gathering. He really seems to process the information, being critical about what he read. At the same time he tends to mix this external information with knowledge from memory. Initially information is used to gain a basic understanding of the problem.

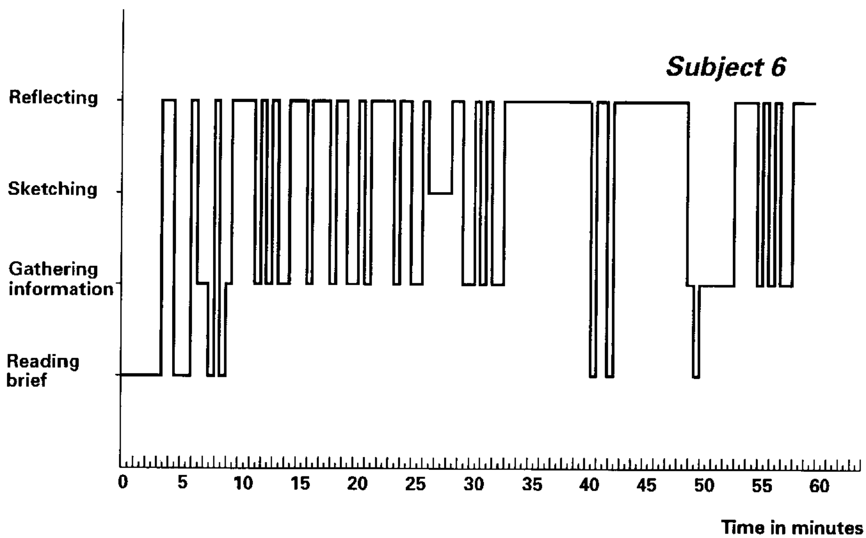

Figure 4.3 'Thinking aloud' protocol of student 6

He starts asking for *information* to "get to know the problem". Next, information is requested to evaluate the existing system. He then goes on to generate ideas while postponing any

evaluation of his ideas. Only after the phase of idea generation does he ask for information to augment the selection of that idea. The kind of information sought is rather similar to some other intermediates (cf. subject 1): wishes of the client, defects of the existing system, evaluation by passengers and cleaners, type of refuse and lay-out of the compartment (see figure 4.4). Yet they differ considerably in their strategy.

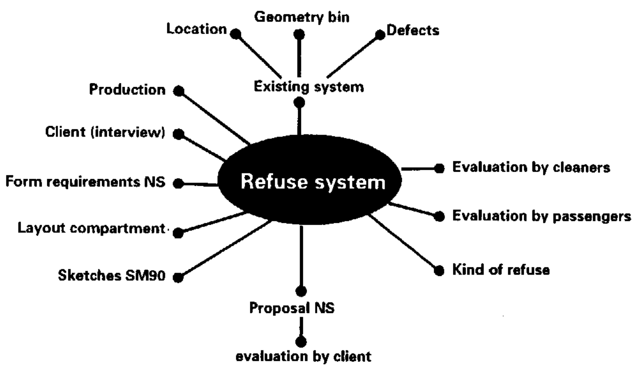

Figure 4.4 Information used by subject 6

Subject 6 uses a 'multiple criterion approach' (Powell, 1987); he asks for information *after* reflecting on (parts of) the problem. That's why he, when generating ideas, is able to select and take into account certain, but not many, design constraints. In table 4.8 the number of constraints, divided into *given*, *derived* and *introduced* constraints, for the six subjects are presented.

Table 4.8 Amount of constraints - given, derived, or introduced - uttered by the 6 subjects in the sample

	Constraints			
Subject	given	derived	introduced	Total
6	23	23	5	51
15	9	21	60	90
17	5	37	8	50
1	3	11	4	18
10	4	24	15	43
11	10	41	21	72

For example, one of his decisions, after 11 minutes, is to give priority to the comfort of the user, i.e. both the passenger and cleaner. From this point of view he goes on to derive constraints from internal and external information.
He really prepares for a phase of *solution generation* (see protocol in appendix VII).

During this (short) period of brainstorming, in which he introduces a number of solutions, he avoids any evaluation of his ideas. *Sketching* is hardly used - later the subject explained that it was not really his forte. Nevertheless, idea generation is done through mental activity, which he verbalizes by thinking aloud and by writing.

Subject 15

Novice
Creativity rating = 7.5
Average design grade < 7
The design solution is presented in figure 4.2b.

Subject 15 demonstrates a rather clear strategy. Immediately after reading the brief he starts formulating and writing constraints to try to define the problem.
At first, the way in which he does this is rather unstructured, but after this short period of 'brainstorming' he formulates the design requirements in a much more organised manner. After 10 minutes he decides to classify the *constraints* according to three issues: manufacturing requirements, user requirements, and form requirements. The change from one phase to the next can be clearly distinguished.
He places nearly all his thoughts on paper during the first half hour by writing, and afterwards by sketching. On examination of figure 4.5 this difference in activities is evident.

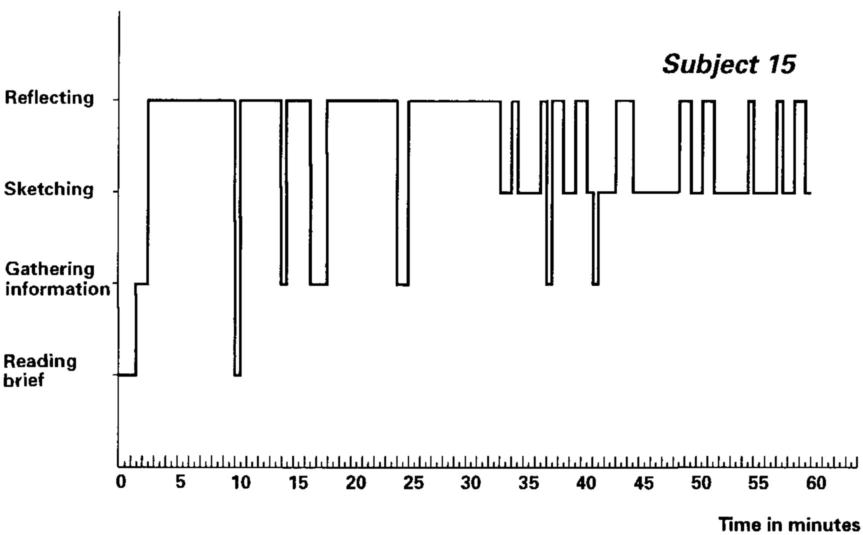

Figure 4.5 'Thinking aloud' protocol subject 15

Although he initially restricts himself purely to the bin, he does come up with an original idea.
More than any other subject he introduces constraints (see table 4.8) based on knowledge he

retrieved from memory regarding system form and function, ergonomic requirements, material, vandalism, bin size and type of refuse.
Hardly any *information* is asked for (see figure 4.6). His first question, on production quantity, occurres after 14 minutes. Other questions are restricted to the production costs, the geometry of the existing bin, the compartment layout, and more specifically whether the number of bins in the new train has been finalised. No information is sought concerning the client or the form of refuse. Constraints regarding these aspects are generated by the subject himself.
To generate *ideas* he starts with the existing system, focusing on the turning mechanism of the bin, however he then halts this approach. After sketching the location of the seats, he concludes that the current location on the wall provides insufficient room. By generating ideas as to other locations he produces a new concept. This concept seemingly has no relationship to the previously produced list of constraints.

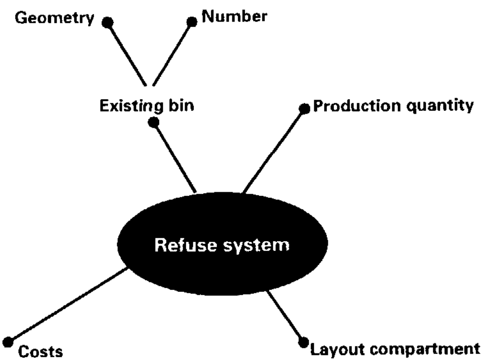

Figure 4.6 Information used by subject 15

Sketching is a very important aid for this subject, he uses it to explore the problem and generate solutions. For a novice he is talented in this respect, performing better than most intermediates. As soon as he begins sketching the restrictive information he produces is eliminated. In appendix VII part of his sketches are presented.

Subject 17

Novice
Creativity rating = 8.5
Average design grade < 7
The design solution is presented in figure 4.2c.

Initially, subject 17's designing technique is fairly similar to that of subject 15. A redesign of the bin is the starting-point in this process. Throughout a total of 40 minutes he explores the context of the problem, but, in contrast with subject 15, without any explicit strategy. He

first introduces his own information on design. Next, with the help of external information, he continues producing constraints regarding the elements of a bin: its opening, the lid, the styling, etc. Thus, in line with many novices, he breaks the problem down into separate parts of the bin to be redesigned. However after 26 minutes he get stuck, and suddenly realises he is designing the existing bin. He continues nonetheless with analysing subproblems like the emptying mechanism and the hinge; and from these aspects, after 42 minutes, he comes up with a number of completely new ideas. In figure 4.7 the sequence of actions is showed.

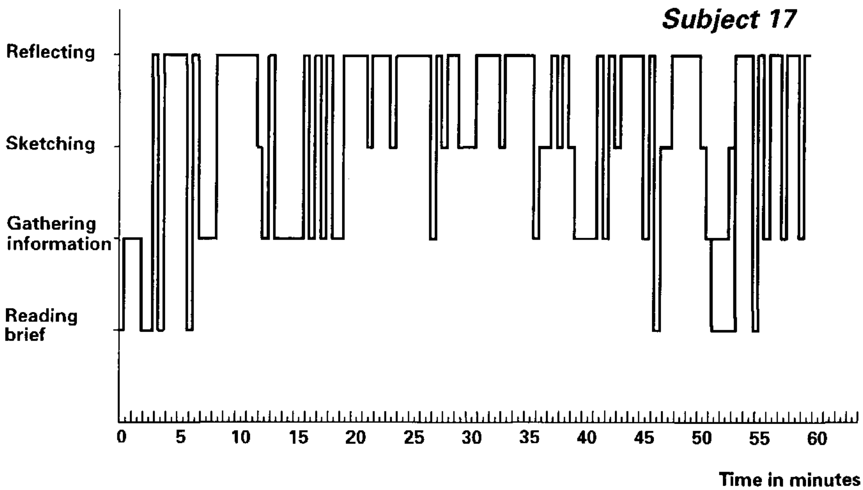

Figure 4.7 'Thinking aloud' protocol subject 17

Generating ideas initially takes place within the framework of the existing bin. After reaching a dead end (i.e. realising he's all but copying the existing design) he generates ideas concerning a change in the whole system.

The requirements formulated early in the process are then used to evaluate the solution. Consequently he realizes that his solution does not conform to the instruction of the manufacturer (Lemmens). Hence, he begins again with redesigning the current bin, generating solutions only for sub-problems. Finally, he returns to the previous solution, and asks the experimenter if he would be allowed to present this to Lemmens. In general, he exhibits flexibility in his decision-making strategy, and is strongly motivated to achieve a innovative solution. Looking at the *information* processing, subject 17 not only retrieves much information from memory, but also asks for more information than most other novices (see fig. 4.8).

Moreover, because he continuously reflects on the problem, he asks only for information which he can incorporate in his knowledge structure and thus his current strategy. The information requested contains aspects of manufacturing, the existing system, the layout of the train, type of refuse, and evaluation by cleaners. No information is sought about the client.

In evaluating and elaborating the selected idea he again asks for further information.

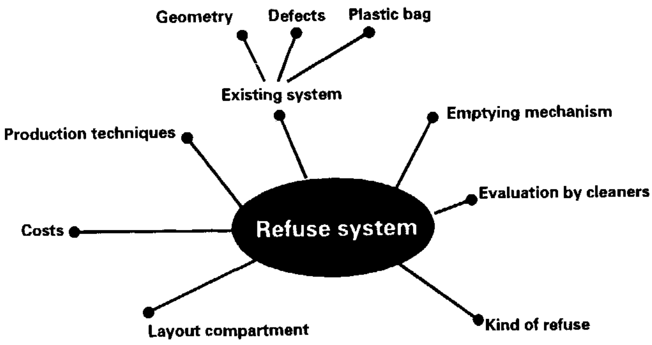

Figure 4.8 Information used by subject 17

Subject 1

Intermediate
Creativity rating = 5.7
Average design grade ≥ 7
Design solution is presented in figure 4.2d.

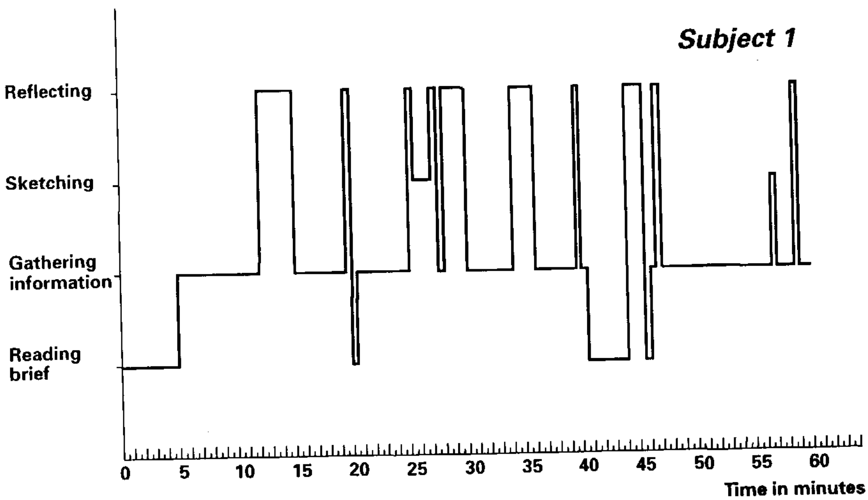

Figure 4.9 'Thinking aloud' protocol student 1

Here again the starting point of the analysis is a rough classification of the protocol into four activities: reading the design brief, gathering and reading information, sketching and drawing, and reflecting.
In figure 4.9 the alternation of these activities during the first hour is presented for subject 1.

In taking decisions subject 1 seems anxious about solving the wrong problem, hence he continuously postpones making any sort of decision. He asks for a considerable amount of information, without really indicating that he is processing it, nor does he reflect on what he was doing. The new information seems separate from an already existing frame of reference. Most of the information requested has no specific goal. He explores the context of the problem, but seemingly without a set plan. Characteristic of the subject is his "thematic vagabonding" (Doerner, 1980, mentioned by Allwood, 1986). He does not complete the (sub)problem or chain of thought to a natural end point, but instead constantly changes to a new aspect of the problem before the old one is completed. In other words, he does not follow an explicit strategy.

In spite of the great amount of information asked for, it is doubtful whether *information* is really *processed*. Moreover, hardly any knowledge on the problem is generated by the subject himself.
When the time spent on asking for information, and reading it, is compared with the other activities (reading design brief, sketching, thinking), the proportion appears considerable. In figure 4.10 the information requested by subject 1 during the first hour is presented. Another indication of the aimlessness of subject's search strategy is the extent to which information is transfered to specifications and requirements.

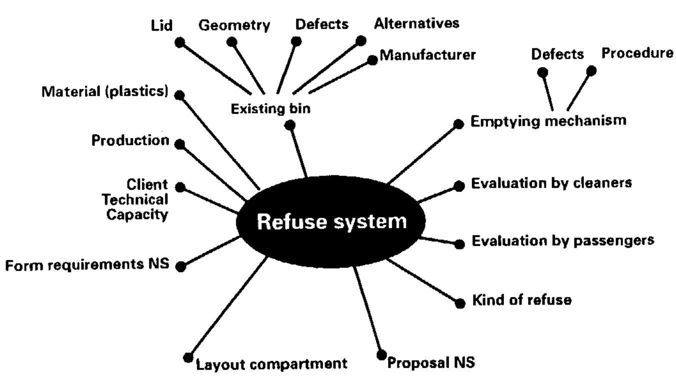

Figure 4.10 Information used by subject 1

The number of *constraints* he derives are limited (the first after 24 minutes), and few in comparison to other subjects (see table 4.8). Constraints introduced by subject 1 are concerned with the location and geometry of the bin, with ease of cleaning, and the necessity

of a lid.
From the beginning subject 1 concentrates mainly on redesigning the bin, and not designing a new system. Hence, his solution space remaines rather small. His final solution is indeed a redesign of the bin. During the first hour of the experiment no *ideas* are generated.

Sketching is hardly used to express the designers thoughts, although a couple of times he motions toward drawing but then withdraw. After 26 minutes the first sketch is made, it concerns the interior of the train, and the location of the seats. After 1 hour he starts sketching again, but this time for a long period.
In the sample of 20 subjects, subject 1's method of designing is similar to two others, one novice (s. 18) and one intermediate (s. 20).

Subject 10

Novice
Creativity rating=4.5
Average design grade <7
The design solution is presented in figure 4.2e.

Characteristic for this particular subject's *strategy* is his *decomposition of the problem* into a number of sub-problems, which he then successively tries to solve. Following reading the design brief he immediately writes a few requirements of a refuse bin, as is given in the brief. After 8 minutes he starts sketching which continues until the end of the session. During sketching he generates alternatives for the separate elements of a bin: the opening system with regard to cleaning, the closing mechanism, the connection to the wall, etc. See figure 4.11.

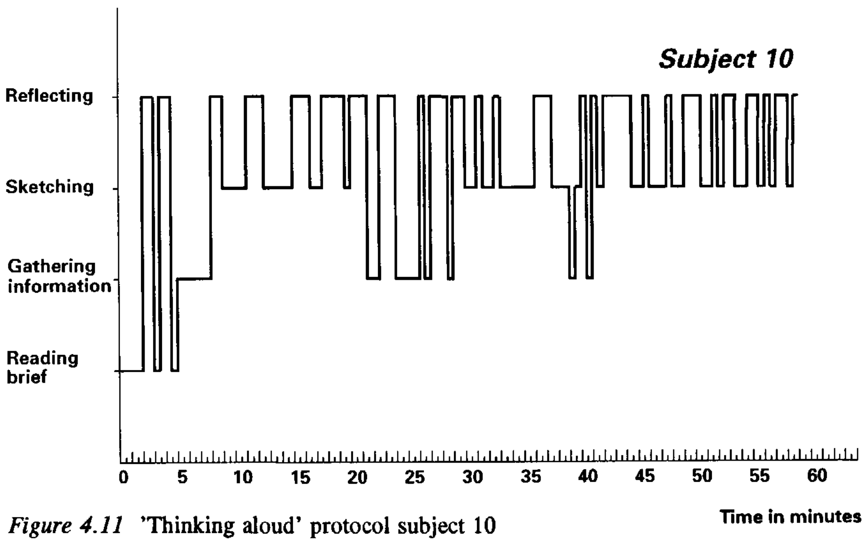

Figure 4.11 'Thinking aloud' protocol subject 10

Parallel to the strategy of decomposing the overall problem another strategy is applied to the subproblems, i.e. 'generate-and-test'. While, for instance, subject 6 postponed the evaluation of any idea until he'd finished this phase, subject 10 is critically testing an idea regarding a sub-problem immediately after generating it. He would then decide to stop or continue generating ideas for that particular element of the problem.

As far as *information processing* is concerned, because subject 10 is only engaged in a redesign of the bin, his problem space and thus information processing is apparently limited. As can be seen from figure 4.12 very little information is requested. Most of his information is retrieved from the design brief, and from activating his own memory. As a consequence the time spent on gathering information is rather short.

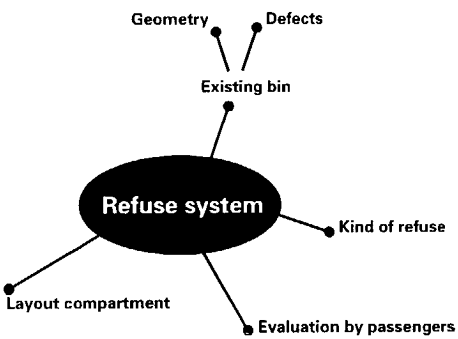

Figure 4.12 Information used by subject 10

The role of *sketching* is evident. Subject 10 behaves in a way which is generally believed to be typical for a designer. He explored the whole problem by sketching alternatives for sub-problems.
However, the difficulty for the subject here is to compose an overall solution. He does not succeed very well in finding a creative solution. The design he creates is rather run-of-the-mill and similar to the existing bin.
Subject 10's method of designing serves as a model for 3 other (novice) subjects in the sample (subjects 3, 4 and 18).

Subject 11

Intermediate
Creativity rating=5.5
Average design grade ≥7
The design solution is presented in figure 4.2f.

The strategy of subject 11 is different from both intermediates (1 and 6) described before.

Firstly, soon after reading the brief she makes a time-table for the activities to be performed:

"½ hour for sketching; ½ hour for cost estimation; then I have 1½ hours for idea+development."

She sticks to the plan well.
Secondly, from the start she aims simply at a redesign of the bin. She uses a 'generate-and-test' approach. Alternation of generating ideas and evaluating those ideas leads to a restriction of the solution space early in the process. Decisions about (parts of) the design are taken without serious consideration. She solves a problem, but it's an easy one. See figure 4.13 for the protocol of subject 11. After 53 minutes she takes a 7 minute break, talking to the experimenter about issues which has nothing to do with the design task.

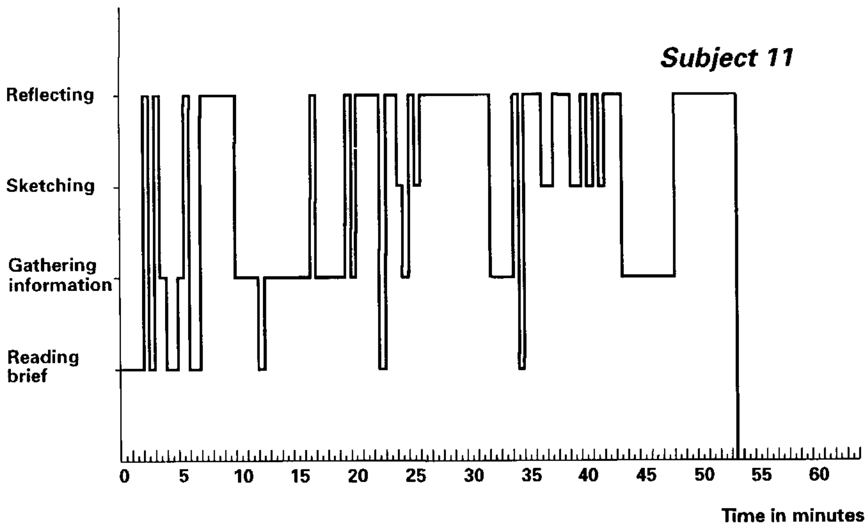

Figure 4.13 'Thinking aloud' protocol subject 11

The information asked for is immediately used to formulate constraints, these constraints played an important role in solving the problem.
Most requests for information (62%) are submitted as confirmation of ideas already formed in the subjects mind. In figure 4.14 the information sources are presented.

In searching for ideas she relies on a few *constraints* as given in the information cards, but more particularly the opinions of passengers and cleaners. The complaint that the bin is too small, together with the fact that a considerable amount of space was taken by newspapers, give rise to the final solution.
The idea ultimately selected is not evaluated in contrast to previous ones. Only during elaboration does she discover that some assumptions were wrong. She then adapts her concept until the solution is not much better than the current design.
In general, subject 11 is too easily satisfied with her idea. Although she has plenty of time,

she does not make any effort to generate any other ideas.
Her way of designing seems subordinate to her time-table.

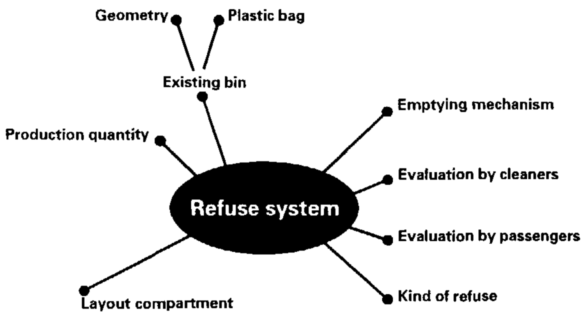

Figure 4.14 Information used by subject 11

4.7.7 *Discussion*

A description of the design process regarding the relationship between knowledge processed and the creativity of the design solution by way of protocol analysis produces a lot of relevant data. However, because a departure from a validated design theory is not yet possible, the data as yet are difficult to interpret. Still, a number of conclusions can be drawn from this study, though they are speculative.

Verbal data

Extensive protocols were recorded. However, the verbal reports of information processing are of course incomplete. Nevertheless, it is felt that the protocols contained sufficient information to make a detailed picture of the novice and intermediate designers problem-solving processes, and answer the research questions. The introduction of an 'information box' allowed for a more objective measurement of information processing.

Creativity of solutions

Measurement of creativity with the 'consensual assessment technique' (Amabile, 1983) provided reliable results, and it seems the rating did not depend on the level of expertise nor the subjects design abilities as measured by the grade point average on their formal design courses. As it turns out design ability is actually negatively correlated with the design's creativity.

Decision making and other strategies

In general, most subjects tried to apply the strategies and methods learnt through their design education, i.e. they began first with a definition of the problem, gathered internal and external information when necessary, derived specifications and constraints, and then tried to generate ideas. However, looking more thoroughly at these basic steps, many differences between subjects were observed regarding their strategies.
An important decision appears to be how the problem is defined. In general there were three options: (1) subjects chose a convergent way of thinking, reducing the problem to simple level; (2) subjects chose a divergent way of thinking, using a 'multiple criterion approach' without loosing sight of the overall problem; and (3) subjects failed to make decisions any decisions. Option 1 was chosen by nearly all novices, but also by at least four intermediates. Option 2 was selected by only a few subjects, novices and intermediates. This option lead to more creative design solutions. Option 3 wasn't really an option, it just befell certain subjects - both novices and intermediates. This always led to poor results. Postponement of decisions was often combined with asking for a lot of information.One of the most interesting findings was that successful subjects did not split up the problem into independent sub-problems, but tried to solve it as a whole.
Most of the current design methodologies look to get a grip on a problem by employing a strategy that decomposes it. This strategy has recommended as a useful approach in mechanical engineering and architecture. However, industrial designing is different in this respect. In this particular domain a problem spans many different aspects (aesthetics, ergonomics, technical- and management factors all play a part), and a high degree of integration is called for. Attempting to see one sub-problem as independent, and solving it separately from the other elements could easily result in an unmanageable amount of restrictions on the rest of the problem and solution, or an unwanted bias in the design. Working on the problem as a whole, and on an allround-concept - continually bombarding it with the different requirements -, could ultimately be a better strategy for this type of problem.
The relationship between constraints and the generation of ideas is a complicated one. It is obvious that some ideas are indirectly derived from constraints, but generally, efforts to reason from requirements often blocked creative solutions.
Compared to other disciplines a number of 'weak' methods can be observed. The so-called 'working-backwards approach' was adopted by half the novices. The strategy of a number of both novices and intermediates was characterized by a 'generate-and-test' method, by which conjectured solutions were used as a means of problem-analysis.
Is there any relationship between the strategy applied and the creativity of the result? Of course, a combination of factors influenced the performance quality. Nevertheless, the data suggest that the more time a subject spent in defining and understanding the problem, and consequently using their own frame of reference in forming conceptual structures, the better able he/she was to achieve a creative result.

Information

The role of information with regard to the design process and its result was mainly dependent

on the subject's problem solving approach. If a subject postponed problem definition, or if he couldn't get a grip on the problem, the information requested or retrieved from memory would not be assimilated into his/her frame of reference. On the other hand, subjects with a clear understanding of the problem, who took time to reflect on what they were doing, incorporated the information into patterns as the process developed.
Also, intermediates asked for more information than novices. With their lack of experience novices treated the design brief simply as a problem they'd solve as part of their second-year design course. Again, the role of the formal education was evident.
The way in which information is offered is seemingly no decisive argument regarding the willingness to gather information. However, in this study no attempt was made to investigate this particular question.

Sketching

Sketching is assumed to be an aid to represent the abstracted knowledge from the problem into 2-dimensional topological and geometric relationships. However the benefit of this aid was different for different subjects, partly dependent on their skill or talent in drawing. There was also a difference between novices and intermediates, the former group using the skill much more extensively. From the data it can be concluded that the use of sketching does not guarantee a more creative result. Some intermediates showed that they were able to generate and manipulate new concepts solely through mental activity.

Chapter 5 Epilogue

5.1 *Introduction*

The general aim of the empirical studies conducted in this book is to extend jointly the scientific base of design methodology and educational design principles. To date several authors have stated that design theory and education is guided too heavily by intuition and practical experience. Because the synthesis of the factors involved in design is poorly understood, in education, the teaching is preeminently focused on analysis (Dixon, 1989; Cross, 1990; Simon, 1979). The focus in this book was primary on *education* in design engineering, the studies being conducted using those particular design students. In education the foundation is laid for design expertise, therefore, it is of great importance that the principles of how to develop and nurture design qualities are clearly understood.

In the preceding chapters a number of studies were discussed to elaborate on the general study aim. In doing so the following research questions were explored: (1) What is design expertise? (2) What is the role of knowledge in design, and what is its influence on performance quality? (3) What characterises the expertise of novice designers compared to designers of an intermediate level? (4) What is the relationship between expertise and performance quality?

As a starting-point in this research project the design process was defined as an information processing activity. The understanding of this activity was mainly derived from literature on problem solving expertise in other domains, such as physics and medicine. In general it is shown the problem solver can be characterised as selecting and inferring problem information from external sources, and activating his own knowledge in order to form an internal representation of the problem. Part of the knowledge will be domain-specific, and the other domain-independent, a more general kind of 'process knowledge'. The kind and content of knowledge used depends on both the domain to which the problem belongs, on the structure of the problem and on the expertise of the problem solver. A considerable amount of the earlier research on expertise is focused on the novice-expert paradigm. The development of expertise is initially related to the learning of *procedural* knowledge; the learning of how to solve a problem well. The theoretical background can be extracted from Anderson's view of knowledge compilation (Anderson, 1983). Production rules based on operator sequences regarding a successful problem solution will be stored, and can be retrieved in order to solve similar future problems. Compilation, thus, results in a reduction in solution time due to large search paths being shortened, a decrease in the need to access declarative memory, and a

speeding-up of rule-firing by reason of rule reinforcement with each successful operation (Holyoak, 1991). When solving a problem, because solution procedures are not yet part of their knowledge-structure, novices apply knowledge in a much more laborious and active manner than experts. Related to this developing expertise is the ability to distinguish relevant from irrelevant information. Studies in domains like physics reveal that experts construct abstract problem representations, in terms of underlying principles, based on well-organised abstract knowledge. Moreover, general knowledge becomes specialised, leading to domain-specific knowledge of problem situations and of detailed strategies. In research on novice-expert comparisons the most striking difference seems to be the adoption of backward (novice) against forward (expert) reasoning. In backward reasoning the problem solver works from the goal or hypothesis backward to the given information. Forward reasoning on the other hand pertains to the strategy starting with the data available and working forward to attain the goal. These two forms of reasoning strategies are often related to another characteristic distinction, that is, the contrast between strong and weak methods. Weak methods or heuristics are often engaged when an adequate knowledge base is missing. Problem representations of novices are based on commonsense knowledge which is mainly domain-independent. Strong methods pertain to task-specific heuristics and algorithms constrained as to the relevant domain knowledge and the solution process used.

The use of a particular strategy is, however, not only dependent on the level of expertise. Of course, in solving routine problems (which is often the case regarding research in this area) the difference between novice and expert strategies is obvious. However, the selection of a certain strategy is also influenced by the structure of the problem, and of the domain-specific knowledge available. As Anzai (1991) states, differences in problem solving goals, for example between physics and medical knowledge, can lead to differences in knowledge structure and thus in inference strategies. In other words, research results regarding domain knowledge in problem solving processes are not universally valid through domains. Especially toward the design domain there is reason to believe that knowledge and methods applied in designing differ from those in other domains. The difference can be reduced to the contrast in the structuredness of the problems. The most outstanding characteristic of the design domain is the nebulousness of design problems. There is no definite criterion for testing a proposed solution, and when a solution is found, no criteria can be derived from it, as in a similar problem something new must be added. Moreover, the problem is not necessarily connected to only one problem space. One consequence being that it's very difficult to distinguish between relevant and irrelevant information. Unlike the solution of well-structured or routine problems to which 'strong methods' like domain-specific algorithms can be applied, solving design problems has mainly to rely on conjectures and weak methods.

Even an evaluation of the design resultant, the artifact, is hardly possible because assessment criteria cannot be defined objectively. Designing aims at generating creative solutions. Because originality cannot be reduced to another origin, new creations cannot be pre-programmed.

Hence, because problem-solving processes in design seems qualitatively different from processes that have been observed in other domains the findings elsewhere are probably not applicable to designing. That's another reason to conduct studies in design regarding the basic

information-handling capabilities of (student) designers, such as encoding, manipulation, and recall of information. In order to simulate the studies in other domains it is necessary to take into account the variables 'expertise level' and 'performance level'. With regard to expertise, in an educational setting it's easy to select novices and intermediates. However, performance level in design is, because no objective criteria are available, difficult to define. Nevertheless, a reliable criterion for performance quality is necessary in order to understand the role of knowledge in a design process that leads to successful rather than unsuccessful designs. As a consequence, before investigating the influence of expertise in design, studies were conducted in order to look for an operational definition of creativity within design. Next, the development of the designers expertise through education was related to the question of what kind of knowledge or expertise, together with more personal characteristics, is likely to nurture optimally creative design.

5.2 *Creativity*

On the basis of literature regarding creativity three assumptions were adopted within this study:

1 The concept of creativity is only meaningful within the context of the domain at issue.
2 A product approach to measure creativity gives the best chance of success for reliable and valid assessment. The assumption by some researchers that creativity is a personality trait was not shared; characteristic of a trait is its stability over time, which is incompatible with the idea that creativity can be influenced by learning. The aim was to use creativity as a criterion for evaluating the design process. Hence, in the context of education a relative criterion, applicable to novice and expert designers was sought; novices can also be creative at their own level of competence. The concept, as defined here, intended only to include product design.
3 Creativity is conceived of as a culturally defined concept, giving further reason to consider measurement of resultant designs as a relative measure.

The *consensual assessment technique* of Amabile (1982) was adopted for the study. Her approach is based on a creativity definition stating that observers who are familiar with the domain will agree which designs are creative and which are not. In order to test the feasibility of the technique the studies, described in chapter 2, were partly conducted to replicate Amabile's research. The designs assessed were made by students, as part of their formal design courses. Results of the studies show that product creativity, illustrated through the high degree of agreement between judges, can be measured reliably. Familiarity with the domain proved important: the more homogeneous the group of observers was, the more they agreed upon the creativity of the designs. An extension of the Amabile studies was related to the question of whether creativity can be considered as a psychological construct which can be distinguished from other constructs. Therefore, in the same studies the relationship between creativity and concepts like aesthetic appeal and technical quality were investigated. The results show that creativity and aesthetic appeal are closely related. However, they also reveal

real differences between both concepts which could be validated by introducing a variable that influences strongly the creativity judgement. The *prototype* of an object or a situation already stored in memory, seems to act as a default value to judge against the creativity of an unknown object or situation. This kind of interdependence was not found between the prototype and aesthetic attributes.
A further analysis of why one design was more creative than another showed that elements of the design process were reflected in the design itself. When judges were asked to verbalize concerning the underlying conditions of creativity, they spoke about the integration of various design dimensions such as form and function, about techniques of styling and elaboration of the design, and about the commitment of the designer as manifested by his willingness to search for new solutions and to take risks. As a consequence part of these conditions are related to the learning process, and as such can be improved. These interview results also seems to confirm the statement of Weisberg (1988), that (1) creativity is strongly influenced by the creator's commitment, that is, strong motivation and persistence, and (2) creative products are firmly based on what came before, i.e. on knowledge about past designs. This second aspect was further explored by directly linking the use of knowledge with performance quality.

5.3 *Knowledge elicitation and analysis*

In studying the role of knowledge in relation to performance quality within the domain of design engineering the use of rigorous research methods and experimental designs is almost impossible. For example methods commonly applied in studying other domain expertise are to ask subjects to recall previously learnt material in relation to the time spent learning, or to measure the speed with which problems are solved. Methods like these are of no use in studying the role of expertise in design, because neither memory performance nor problem solving speed are clearly determining factors regarding its quality.
Until now studies within the domain are rare. Research methodology, with regard to the investigation of expertise, refers to various elicitation techniques together with adequate ways of analysing the elicited data. However, it is still unclear which technique is best suited for what kind of knowledge (Schraagen, 1986).
In this study one of the aims was to explore these methodological issues. Therefore, different elicitation techniques were used as well as different techniques for the analysis. The study began with *retrospective* data from first-year students. Following that, a protocol study was conducted in order to explore the relationship between expertise and creativity.

5.3.1 *Retrospective data*

In a semi-longitudinal study the 'learner reports' of a number of design students were gathered during the year. These reports, written during and after the four design projects in the first year course, were part of the students formal courses, i.e. not introduced for the sake of the experiment. In the reports students expressed what they'd learnt through the project

("I learnt that.."; I learnt how.."). The elicited knowledge was only part of the increase in domain knowledge, but it could be used and analysed in a relative sense , i.e. as compared with the knowledge elicited in this way from other students.
The analysis of the elicited knowledge was based on a classification of knowledge categories, derived from the relevant literature. This classification had two overall dimensions; the first one was based on the aforementioned distinction between domain-specific basic academic knowledge, and domain-independent general process knowledge, which together provide the necessary design knowledge. The second dimension was mainly based on the distinction between declarative and procedural knowledge, supplemented by two other categories; knowledge of situations and strategic knowledge. The two dimensions produced a matrix of 12 cells.

The use of the knowledge classification encountered great difficulties which were not foreseen.
Firstly, methodological analysis showed that the encoders of the learner reports were not very reliable judges. The best results were obtained by two psychologist encoders, with a proportion of about 50% agreement. As is mentioned previously, the disagreement between the encoders was caused by idiosyncratic aspects of the encoders, by the complexity of the knowledge matrix, and also by the content of the written material.
A second, replicative, study with more detailed data from another first-year group revealed that the use of the knowledge classification as an encoding system again led to a rather low inter-rater reliability. It seems, the encoding system together with the coded material (the learner reports) were too difficult to handle - giving too much room for confusion.
As to the validity of learner reports there were two main disadvantages. One is that most of the reports were written after the students had finished their project. Some projects took 6 weeks, so what is remembered may have been limited. Do these reports contain superficial data, or just detailed high-lights? A second problem with written reports was, that even if the experiences elicited were reliable, they might represent only a fraction of the total knowledge acquired.
Looking at the content of the reports, almost 80% of the learning experiences were encoded as *declarative* knowledge. This can probably be accounted for by the frequently reported finding that procedural knowledge is not accessible to conscious awareness. As Lewicki et al. (1988) propound, the learning of basic cognitive and procedural knowledge involves the acquisition of complex processing algorithms of which the subject is unaware. He/she acquires some form of 'working knowledge' about patterns of stimuli and how to process them, but however is unable to articulate such algorithms.
As a consequence of the poor encoding system reliability and the skewness of the form of knowledge reported, a less detailed analysis could be performed, reducing the classification of twelve knowledge categories to only three, i.e. domain-specific knowledge - basic knowledge and design knowledge respectively -, and domain-independent process knowledge. The analysis was based on the codes about which the encoders agreed. The data show that during the year students concentrated more and more on the learning of domain-independent process knowledge, while domain-specific basic knowledge was neglected somewhat. In both

studies performed this tendency was supported. It is assumed that practical training in design lead to the acquisition of weak methods and knowledge of underlying design principles. Secondly, concerning the overall results of the first study, and in nearly all separate design projects of the second, the creativity of the designs appears to be related to the amount of process knowledge elicited. The correlations were not significant, but a trend was observed; subjects whose designs were rated higher regarding creativity, on average, reported a higher amount of general process knowledge.
Another interesting finding is that the same students did not design creative products all the time, i.e. product creativity seems not always related to outstanding talent, but will also depend on the motivation of the person and on the task features.

5.3.2 *Protocol study*

The second approach to explore the role of knowledge in relation to creativity in design was through actual observation of student design processes. In a protocol study this relationship was studied together with the influence of different levels of expertise, defined by schooling grade (2nd-years=novices versus 5th years=intermediates) and performance level in the formal design courses.
A rather unexpected result of the study is that expertise is barely related to the creativity of the design solutions; and if there is any relationship at all, it is in the opposite direction. Higher grades in formal design education apparently do not guarantee a more creative performance.
However, there were differences between subjects influenced primarily through design expertise. Firstly, there was a quantitative difference regarding the information used by novices and intermediates. On average intermediates asked for much more information than novices. This finding is related to the way subjects explored and defined the problem, trying to build a mental representation. Secondly, most intermediates seemingly displayed a kind of forward reasoning: (1) They performed a knowledge-based heuristic search into the problem space, and (2) information was requested and elaborated on. Most novices on the other hand worked backwards from the goal: (1) They reduced the problem soon after receiving the brief to a redesign of the refuse bin, and (2) information was scarcely sought, nor was much knowledge activated, and (3) they broke the problem down into subproblems, and solved these individual subproblems first before returning to an integrated solution.

In general novices seems to apply a strategy of 'generate and test' with the help of their sketching technique. They were motivated by designing something new without realising the problem to be solved. Information processing was difficult to observe, because they lacked the appropriate knowledge base. The few novices who tried to construct an elaborate representation, failed to generate a creative solution. In short, novices could only perform the task at their own level of competence, i.e. by applying the same strategy as they would during their formal design course. The few exceptions from this trend were subjects which have a high creativity rating.
Most intermediates are working knowledge-based in that they try to supplement their own

knowledge with a considerable amount of external information. However, half of them fail to assimilate and integrate the information asked for into an elaborate problem representation. A similar finding was reported by Boshuizen (1989) in studying medical expertise. Intermediates in her study were also actively and consciously involved in building up an elaborate internal representation, however, because time was limited, their ability to activate knowledge was impeded. Unlike experts, intermediates do not apply knowledge quickly and automatically. Moreover, in formal education, design project deadlines are never as restricted as in the experiment. Thus, a time restriction may have influenced some intermediates. Nevertheless, the other half of senior students were able to manage their design process in such a way to produce satisfactory design solutions. They designed in the fashion expected of experts. It seems differences between subjects are to a great extent dependent on individual capabilities.

Analogous to studies in other domains the phrases 'forward' and 'backward' reasoning are used to describe the particular strategy of each subject. However it is unclear whether reasoning is really the correct description of what is happening. Forward reasoning is only possible if the problem solver is able to filter out relevant information or domain knowledge; without such a mechanism forward reasoning will be prone to failure (Patel & Groen, 1991). In the studies conducted here nearly all subjects began by using this form of reasoning, but then half of them got stuck, and continued to gather information without being able to process it. Ultimately they changed to a kind of backward reasoning by generating redesigns of a refuse bin, starting with sketching the present one.

Finally, is there any relationship between the design process and the creativity of the design solution?

The process was investigated initially in terms of four activities, i.e. reading the design brief, gathering information, sketching and reflecting/thinking on the problem. As regards the performance quality, a significant correlation was found between the time spent reflecting on the problem in the first part of the design process and the creativity of the result. This relationship is, as yet, difficult to explain. In order to construct a proper mental representation of a design problem, it may be important to begin by structuring your own thoughts about it. Subjects who devoted most of their time to gathering information or sketching possibly failed to develop a structure to serve as a guide for further exploration.

A second aspect related to creativity in design is the ability to select relevant information particular to the design problem. In other domains such an ability is generally attributed to experts, however here this characteristic was not demonstrated. Of course, in solving ill structured problems it is very difficult to define exactly what is relevant and what not. Nevertheless, with regard to the current design problem, it should be expected that designers will develop strategies to quickly differentiate information of low and high relevance. As mentioned before novices were unable to activate any knowledge due to their inexperience. But as regards intermediates the analysis of results suggests that the subjects who designed more creative products were better able to discriminate between relevant and irrelevant information. Intermediates with low product-creativity-ratings continued to sum up a number

of constraints, without looking through the inconsistencies in the information provided. Again, they apparently lacked a clear goal, and so postponed the real designing.

It can be questioned whether expertise must be analysed in terms of novice-expert differences. In the protocol study here the level of expertise was not related to performance quality, a considerable number of intermediate designers achieved only mediocrity. Moreover, in contrast with studies in other domains there was no indication at all that a higher level of expertise benefits problem solving ability.

5.4 *Educational implications*

The educational programme in all academic disciplines emphasises primarily the teaching of domain-specific basic knowledge. In design engineering this basic knowledge pertains to components like engineering, ergonomics, aesthetics and styling, and innovation management and marketing. But secondly, as Simon (1973) states, part of the professional training and subsequent learning has to be directed to organising the process in such a way that the major interactions among components will be correctly managed. In other words designing is, to a great extent, the integration of basic knowledge into a design solution. Moreover, the solution must add something new to the designed world because design problems are, by definition, ill-defined as creativity cannot be accomplished through existing solutions.
The conventional way of teaching the integrative design activity is to offer 'learning-by-doing' design courses, in which real design practice is simulated. Students are taught the same kind of design methodology, a collection of heuristics which should improve their design ability. The design methods employed are derived from prescriptive models of design, and from designers' practical experience. To date very few empirical studies regarding design methodology have been conducted within the domain of design engineering. Thus, the adequacy of such methods has not been systematically evaluated. Due to lack of research the studies described in this book were aimed only at exploring the design activity in relation to knowledge and performance quality. Therefore, the conclusions based on these studies can only be *speculative*, and need to be studied in more detail.

The way modern design courses are put together show, in the author's opinion, various shortcomings. The design process consists of alternating phases of analysis and selection on the one hand, and of integration or synthesis on the other. Analysis pertains mainly to the activity of information processing early on in the design process, and to the evaluation of possible solutions. The integrative ability is important in selecting relevant information and in generating ideas. One of the educational principles based on learning theories is the importance of feedback to the student. However, particularly in academic design education, there is a greater chance that the analytical aspects will receive considerably more attention by way of feedback, than the integrative. The integrative aspects are neglected because only 'weak methods' are available. The protocol study conducted here revealed that a considerable number of students with intermediate expertise failed to integrate their knowledge into a

design concept. The point that this shortcoming is also found in other domains, such as medical expertise, does not alter the fact that education can try to better prepare this ability to students. In domains where problems are structured better (i.e. where strong solution oriented methods can be taught and employed) an important characteristic in the development of expertise, to shorten problem solving search paths, is the acquisition of 'chunks' or 'scripts' of problem situations. Conversely the design domain is characterised by ill-structured problems, where the development of a students knowledge of problem situations can be adequate if he/she is offered a large variety of design tasks. Creative designing often means a very small deviation from existing solutions, but in order to make such a small step knowledge of all kinds of similar problem situations is necessary.
In short, the development of adequate knowledge structure representations should be the primary aim of design education. Patel & Groen (1991) considered this the first stage in the development of expertise. A second stage should be the development of ways of distinguishing between relevant and irrelevant information surrounding a problem. In this study the inability to discriminate between these two kinds of information was obvious. Of course, in designing it is difficult to filter out necessary information because predicting whether information is relevant or not, regarding a particular problem, is almost impossible. Nevertheless students should be taught how to search for and to select information, and how to use the resultant relevant presentations in an efficient way; by Patel & Groen indicated as the third stage in the development. A recommendation for further research would be to describe this developmental process in design.

Another finding of these studies is the role of domain-independent process knowledge in generating creative solutions. The educational process should focus on teaching the student how to organise and manage his or her design process; that is, students should be aware of what relevant and important knowledge can be abstracted from design projects to be applied to future projects, and what methods are useful in implementing knowledge to aid design. In this study, due to an excessive amount of information which they wanted to process, too many students postponed idea-generation. The more they overloaded their *working*-memory the less room they had for integration and idea generation. A method of unburdening working-memory is the employment of an external memory. Visualisation by way of sketching or drawing is the most obvious tool designers have. In design education this skill is trained intensively. Nonetheless in spite of excessive practice most intermediates delayed sketching until they'd finish a lengthy period of information gathering. Novices to the contrary displayed the opposite approach. It seems, the sketching postponement was a consequence of intermediates problem-oriented approach. Because no relationship was found between the point when sketching was initialised and the creativity of the solution, in education, not only drawing *skill* but also methods of idea generation through sketching should be encouraged (Muller, 1991).

Finally, creativity, being the primary area of interest in these studies has been dealt with excessively. In design education, creativity should be given high priority. Design aims to innovate, to add something new to what already exists. Thus, in training and assessment more

attention must be paid to this aspect. The student marks showed a low relationship with regard to creativity, while considerable correlation with technical quality indicates that more priority is given to this attribute. Of course, the technical aspect is important, as it augments basic design expertise. But on the other hand creativity must also be nurtured as a basic part of this expertise. This attribute seems to rely on the capacity to integrate existing knowledge from various sources and then to transfer what has been learnt to new knowledge.

Creativity in this study proved to be a measurable product criterion. Moreover, in exploring the relationship between information processing and product creativity, interesting data were gathered showing a connection between them. Further research will now be conducted in which professional designers perform the same design task, while at the same time the encoding of knowledge elicitation is done more rigorously.

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Appendix

Appendix I

Table A.I.1 Varimax rotation after factor analysis, on creativity measurement in study I. Two product types assessed on seven attributes

Attribute	Computer cabinet		Telephone booth	
	Factor I	Factor II	Factor I	Factor II
Design Creativity	.29	.81	.91	.34
teacher Prototype	.82	.52	.67	.71
Attractiveness	.96	.20	.60	.78
Interest	.96	.00	.34	.93
Techn. quality	.08	.95	.81	.46
Expressiveness	.81	.45	.74	.65
Integration	.74	.64	.74	.63
% of variance explained	71.5	18.0	89.1	6.0
Design Creativity	-.00	.51	.24	.75
student Prototype	.93	-.05	.76	.62
Attractiveness	.82	-.46	.92	.32
Interest	.78	-.54	.98	.02
Techn. quality	.09	.91	.08	.85
Expressiveness	.85	.30	.67	.67
Integration	.85	.24	.71	.63
% of variance explained	51.9	24.1	71.1	15.0
Math Creativity	.85	.07	.82	.32
student Prototype	.86	.42	.82	.50
Attractiveness	.44	.84	.52	.83
Interest	-.19	.95	.11	.97
Techn. quality	.85	-.23	.81	.00
Expressiveness	.94	.07	.90	.37
Integration	.91	.16	.85	.33
% of variance explained	61.3	24.5	72.0	14.7

Table A.I.2 Varimax rotation after factor analysis, on creativity measurement in study III. Three product types assessed on seven attributes

	Telephone booth		Shop display		Drill holder	
Attribute	Factor I	Factor II	Factor I	Factor II	Factor I	Factor II
Creativity	.93	-.14	.98	-.11	.89	.42
Prototype	-.07	.81	-	-	-	-
Attractiveness	.88	.37	.95	.28	.78	.57
Interest	.96	.14	-	-	-	-
Technical quality	.26	.81	.06	.99	.46	.89
% of variance explained	56.4	26.0	63.8	34.2	88.8	7.1

Appendix IIa

Table A.II.1 Scores on the Creative Product Semantic Scale (CPSS) for 2 high-creative and 2 low-creative products; averages and (standard deviations)

Attribute	Product 1 Low PCR	Product 2 Low PCR	Product 3 High PCR	Product 4 High PCR
Novelty	$\bar{x}$ *(sd)*	$\bar{x}$ *(sd)*	$\bar{x}$ *(sd)*	$\bar{x}$ *(sd)*
Original				
Exciting - dull	6.50 (.53)	6.70 (.48)	1.80 (.63)	2.10 (.57)
Zippy - bland	6.40 (.70)	6.60 (.70)	1.90 (.74)	2.10 (1.10)
Fresh - overused	6.90 (.32)	6.30 (.95)	1.50 (.53)	1.40 (.52)
Eccentric - conventional	6.80 (.42)	6.60 (.70)	2.20 (.92)	1.60 (1.07)
New - old	6.30 (.48)	5.90 (1.20)	1.50 (.71)	2.00 (1.15)
Novel - predictable	6.90 (.32)	6.00 (1.49)	2.10 (.57)	1.90 (.57)
Unusual - usual	6.60 (.52)	5.50 (1.84)	1.80 (.63)	1.80 (.63)
Unique - ordinary	6.70 (.67)	6.20 (.92)	1.80 (.63)	2.00 (.67)
Original - commonplace	6.70 (.67)	6.70 (.48)	1.60 (.70)	1.40 (.52)
Surprising				
Startling - stale	6.50 (.97)	6.40 (.97)	1.90 (.74)	2.00 (.82)
Surprising - customary	6.60 (.70)	6.00 (1.56)	1.80 (.92)	1.60 (.70)
Astonishing - commonplace	6.80 (.42)	6.70 (.48)	2.50 (.85)	2.10 (.74)
Astounding - common	6.70 (.95)	6.80 (.42)	3.40 (.97)	2.90 (.74)
Shocking - ordinary	6.60 (.97)	6.40 (.70)	3.30 (.67)	2.40 (.70)
Unexpected - expected	6.10 (1.45)	5.70 (2.11)	2.50 (1.08)	1.90 (.74)
Germinal				
Trendsetting - warmed over	6.80 (.42)	6.10 (1.20)	2.00 (.82)	2.30 (1.49)
Revolutionary - average	6.60 (.97)	6.50 (1.08)	2.50 (.85)	2.60 (1.65)
Radical - old hat	6.80 (.42)	6.40 (.70)	2.10 (.74)	2.10 (.74)
Resolution				
Valuable				
Priceless - worthless	5.70 (1.16)	5.90 (1.45)	3.20 (.79)	3.50 (1.08)
Valuable - worthless	5.50 (.97)	5.80 (1.40)	2.20 (.42)	3.30 (1.42)
Important - unimportant	6.50 (1.27)	5.90 (1.45)	3.10 (.88)	3.40 (1.17)
Significant - insignificant	6.20 (1.03)	6.40 (1.07)	2.60 (.84)	3.10 (.99)
Essential - inessential	5.40 (1.17)	5.90 (1.45)	2.70 (1.06)	3.90 (1.37)
Necessary - unnecessary	5.40 (1.07)	5.70 (1.77)	2.90 (.99)	4.60 (1.51)
Logical				
Logical - illogical	2.70 (1.34)	3.80 (2.62)	3.00 (1.49)	4.10 (1.66)
Makes sense - senseless	4.90 (1.60)	5.50 (1.58)	2.30 (.48)	4.00 (1.49)
Correct - incorrect	4.30 (2.16)	4.40 (1.84)	2.70 (.67)	3.60 (1.35)
Appropriate - inappropriate	3.90 (1.97)	4.90 (2.08)	2.20 (.63)	3.50 (1.51)
Adequate - inadequate	3.20 (1.48)	4.10 (1.52)	3.10 (1.60)	3.70 (1.49)
Useful				
Effective - inneffective	3.20 (1.48)	4.00 (2.49)	2.50 (1.18)	3.70 (1.57)
Functional - non-functional	2.20 (.92)	3.20 (1.99)	2.70 (1.42)	4.00 (1.56)
Feasible - unfeasible	2.40 (.70)	3.90 (2.18)	2.00 (.82)	3.70 (1.64)
Operable - inoperable	1.40 (.70)	1.60 (.52)	2.60 (.97)	2.60 (1.07)
Useful - useless	4.00 (1.56)	5.20 (1.99)	2.40 (.84)	3.70 (1.57)
Workable - unworkable	2.70 (1.25)	2.80 (1.32)	2.60 (1.26)	3.30 (1.06)
Usable - unusable	2.30 (.67)	3.50 (2.27)	2.20 (1.23)	3.80 (1.69)
Durable - flimsy	1.90 (.99)	2.60 (1.26)	5.20 (1.32)	3.50 (1.27)
Substantial - insubstantial	4.30 (1.64)	4.60 (2.01)	2.60 (.97)	3.60 (1.90)
Table continued				

Table A.II.1 continued

Attribute	Product 1 Low PCR	Product 2 Low PCR	Product 3 High PCR	Product 4 High PCR
	$\bar{x}$ *(sd)*	$\bar{x}$ *(sd)*	$\bar{x}$ *(sd)*	$\bar{x}$ *(sd)*
Elaboration an Synthesis				
Organic				
Orderly - disorderly	2.20 (1.23)	1.60 (.52)	3.50 (1.51)	3.60 (1.78)
Arranged - disarranged	2.40 (1.35)	1.50 (.71)	4.70 (1.83)	5.20 (1.75)
Organized - disorganized	3.20 (1.32)	2.00 (1.05)	3.10 (1.20)	4.40 (1.58)
Formed - formless	5.90 (.99)	6.20 (1.32)	2.20 (.92)	3.50 (1.35)
Complete - incomplete	3.00 (1.49)	3.10 (1.45)	2.80 (1.55)	3.20 (1.14)
Whole - partial	2.30 (1.16)	2.50 (1.72)	3.00 (2.05)	3.40 (2.12)
Sufficient - insufficient	5.50 (1.51)	5.30 (2.00)	1.30 (.48)	3.20 (1.40)
Perfect - imperfect	5.70 (1.16)	6.20 (1.23)	3.00 (1.25)	4.70 (1.16)
Elegant				
Harmonious - jarring	3.60 (.97)	3.40 (1.65)	2.80 (1.69)	3.10 (1.73)
Graceful - awkward	6.20 (.79)	5.70 (1.57)	1.80 (.79)	3.60 (1.43)
Charming - repelling	6.00 (.67)	5.80 (1.14)	1.70 (.67)	2.60 (.97)
Elegant coarse	6.00 (.82)	5.10 (1.20)	1.60 (.70)	3.70 (1.57)
Attractive - unattractive	6.30 (.95)	6.60 (.70)	1.60 (.70)	2.80 (1.48)
Complex				
Intricate - simple	5.90 (1.60)	5.80 (1.23)	3.90 (1.10)	3.80 (1.14)
Complex - simple	6.00 (1.05)	5.70 (1.95)	4.10 (1.10)	3.50 (1.58)
Ornate - plain	6.50 (.53)	6.80 (.63)	1.90 (.74)	3.50 (1.65)
Complicated - straightforward	6.20 (1.14)	5.50 (1.78)	3.70 (1.16)	3.40 (1.17)
Interesting - boring	6.80 (.42)	6.70 (.67)	1.70 (.82)	2.40 (.70)
Understandable				
Meaningful - meaningless	6.30 (.95)	6.40 (1.07)	1.90 (.74)	3.40 (1.07)
Understandable - mysterious	1.90 (.99)	2.40 (1.65)	3.80 (1.75)	3.90 (1.20)
Intelligible - unintelligible	2.60 (1.35)	3.40 (2.17)	2.30 (.82)	3.30 (1.42)
Clear - ambiguous	3.30 (1.89)	4.20 (2.15)	2.30 (1.57)	3.10 (1.60)
Explicit - implicit	3.50 (1.84)	3.40 (2.01)	2.20 (.79)	2.70 (1.77)
Self-explanatory - unexplained	2.40 (1.71)	4.00 (2.36)	2.80 (1.62)	5.20 (1.14)
Well-crafted				
Skillful - bungling	5.30 (1.42)	4.80 (1.48)	2.00 (1.05)	3.90 (1.73)
Well-made - botched	5.10 (1.52)	4.40 (1.84)	2.10 (.88)	5.00 (1.56)
Well-crafted - crude	5.50 (1.35)	5.00 (1.33)	2.70 (1.25)	4.50 (1.51)
Meticulous - sloppy	4.90 (1.66)	4.00 (1.56)	3.10 (1.52)	5.00 (1.41)
Skilled - unskilled	5.30 (1.57)	5.50 (1.65)	2.60 (.97)	4.20 (1.23)
Expert - inept	6.60 (.70)	6.10 (1.45)	2.80 (1.40)	4.50 (1.58)
Careful - careless	5.70 (1.57)	4.80 (2.15)	1.70 (.67)	4.70 (1.42)

Appendix IIb

Pair-comparison of low and high creative products; an interview as an example

Judge 6

Product 1 (Low-creative)

A rather geometrical angular thing, very simple designed.

Colour: I think the yellow inside surface is awfully annoying.

It's very practical; everything is put together and voor de for the rest little attention is paid to the form-and-style aspects.

The structural construction: it's a shed. It's an example of thinking from the well-known; such as you in the first instance would construct from a couple of shelfs. That's how it looks like: that telephone-stickers at the window are put there with the aim to show it's a telephone booth. It's designed with a one-track mind.

Product 3 (High-creative)

The forms and styling, the elements from which it is constructed, are much more playful than the low--creative product on the left. More playfully linked together. The use of the material itself doesn't matter much. The transparancy of this product looks much more sparkling.
(*Sparkling, playful?*)
The forms which are used; for example the two forms of the ear which are used; I like it because it's funny; another example is the railing that is curved; I think these are things you can lean against. The details are the funny things. I cannot see very well how it's made at the upper side. Perhaps the designer has also worked some jokes into that part.
(*The form defines the creative element in the design?*) I think it's the structural construction.
The designer has reflected for a longer period upon this design; he has thought about the act of phoning.

Product 2 (Low-creative)

It's typically an existing product.

With this design I really have the feeling that it's old hat.

Here he or she tried to polish the primitive form, but that's not creative.

Product 4 (High-creative)

It is again really different.
(*With respect to the form?*) Yes indeed. It is not really a telephone booth...not really a shed-shaped telephone booth with the cube as a basic form.
The most important feature of creativity is here: it differs from the well-known. (*It must be moer than only differing from the well-known, because the extreme is not necessarily creative*). No, no, it's more. The design has something funny, it's a festive pavilion. (*Do you take the functionality into account?*) Well, I don't when I judge it on creativity. But it is possible that it is involved.
Form features:: That circular roof, it's a nice idea. That entrance, likely it must suggest a gate.
The colour-use is very important here. Many colourful areas. All vivid colours. (*Is creativity defined by general features or is it obect-dependent*). It is object-dependent; for example both creative designs are circular. It's hardly creative when you at once thinks in images like a box. The circular shape generates a nice solution, which makes the product more attractive. Then it's indeed a creative expression; that you don't think in a way that you stick to the first idea; that you think on a deeper level which allows you to let the idea go.
Creativity: let go your normal way of thinking.
(*What about concepts like arousal and logic?*) Arousal has to do with the unexpected, when you are confronted with something that differs from the well-known. With that you evoke arousal. Or something that you desire very much which also evokes arousal. It's difficult to connect it with this design. If you must judge it, then your opinion here is: it is a funny design in contrast with the other one.
(*Humour?*) Yes, humour; it doesn't express something serious, it is a festive thing. When you should see it in the street, it is really a marquee.

Appendix III

Examples of learning experiences from first-year students, encoded in a knowledge category according to the matrix of chapter 3, table 3.1. The first dimension of the matrix is divided into basic, design and process knowledge; the second dimension into declarative, procedural, situational and strategic knowledge.
My specification was o.k., but it was told that some aspects, such as bending a thick pipe, are difficult to practice.

1.1
Basic knowledge, declarative

Through information gathering I learnt more about materials and about connecting and processing techniques, but I don't know yet about cost estimation.

I learnt that I hardly know anything about connection methods and that in designing it is very important to know a lot about it.

When dealing with connections I often complicated the situation. I thought of all kinds of constructions with nuts and bolts, while most could simply be connected with glue. I must take up the available catalogue and check which connection devices can be used.

I did not learn enough techniques to make a rendering.

2.1
Basic knowledge, procedural

I learnt the first steps in making a rendering.

I learnt how to operate a glue pistol.

Wood cannot be bent around. I learnt a method, using single boards, by which it looks around.

When you work in a group it is important that you allocate the work; that dedicates yourself to the group (not making drawings for yourself); it is also important that you present your ideas to the group and how you think it should be differently.

Through this project I also learnt how to compose a report, and especially that because it's so important, you must not delay writing the report till the end.

3.1
Basic knowledge, situational
Technical problems can often be solved by looking at constructions which surround you.

When painting the model, if the paint is going to flake, then use paint which adheres better or paint it at latest.

In order to connect cardboard shelves in my model, I glued with a glue pistol a home-made cardboard profile to the various parts. Because the glue dries very quickly not all the parts which had to be connected, fitted very well. My learning experience: if you use a glue pistol, then the connecting parts must be placed together quickly and accurately.

In making a prototype I must take into account the absorption of the paint into the cardboard. Through that the colour changed. Perhaps I ought to use 3 mm cardboard with a white coating.

May be in that case the prototype had been more representative and attractive.

4.1
Basic knowledge, strategic
In order to finish and present a report in time I must keep this report after every activity.

I learnt that you must begin with making a good guide in aid of your own tutoring.

The copying of the lay-out took much time, because I made a lot of test copies; this caused piles of paper through which I forgot to copy something. First of all I must make and order the originals and next plan and write down what exactly I want to copy.

Starting sooner with typewriting and not postponing it at latest saves time and prevents a lot of stress.

1.2
Design knowledge, declarative
In detailing the selected concept we had to define the necessary material and the way of manufacturing. Because I don't know yet the costs and the possibilities I'm afraid that my design concept will probably be rather expensive. I must gather more information about machining methods and prices of materials.

The elaboration of concepts takes much time. The size determination with regard to ergonomics is very difficult. In defining the sizes of the product you must observe it both 2D and 3D. This is difficult because of the 2D reproduction.

I must take care of a better survey through which I can make connections to other topics in my concept.

I introduced my own idea about the fastener, but it was dissuaded to use it; it was too cumbersome. Hence, stick to well-known, used solutions and avoid needless trouble.

Make a proof before producing a prototype.

2.2
Design knowledge, procedural
Now I have an idea of what must be the content of a presentation report: well-made, clear drawings concerning the use of the product and the strong sides of it; next a 'marketing' story about why my design is exactly the suitable, clever, well-considered, ergonomic one you need. In other words, you must present your design in the right way.

I learnt how to make a scale model. The best way to do this is with the help of good technical drawings.

I learnt to describe the problem in the right way. It is not a matter of saying: "A problem is that the telephone hangs too high", but you must add: "... which is a problem for small people and for people in a wheel-chair". Through explaining 'why' the more you emphasize the problem.

Although my detailing was in fact clear with regard to completeness, it left much to be desired. It was scantily and not a very attractive presentation of the telephone booth. The detailing must be more extensive with clear information about topics like colour, manufacturing and special elements (ash tray, clamp, etc.).

I also learnt much about model making, such as the processing of perspex. You can do it easy with a fret-saw and a little piece of sand-paper; and I learnt about the painting of big surfaces. That works very quickly by using a small, smooth paint roller.

3.2
Design knowledge, situational
A model is very useful because it can be observed as a whole; it's easier to evaluate and to solve subsequent problems. Afterwards the model can be used in the presentation.

I learnt that perspex, plexiglass and acrylic glass are better materials to simulate window-glass than transparent sheets. These real materials are more solid.

In the idea-generation phase it's wise to generate many variations on a number of basic forms. By basic forms I mean square, circular, polygonal or twisted.

When the model shows that some constructive features are impossible, you should better generate a new solution instead of sticking to the old construction. In my case: I planned to glue a frame of plastics. However, it proved to be a waste of time. Then I used tape which was a better idea.

I noticed that I introduce sizes too early without serious consideration. I doesn't mean the height of the writing-desk but the outward sizes. Only in the last minute I detected that the booth was not wide enough to let a wheel-chair through. I always must keep in mind what the characteristics of the consumer group.

If I want to make a model according to the right proportions, then I must take into account the measures of the available materials which must be used.

4.2
Design knowledge, strategic
During constructing the test model I realised that certain details are not yet elaborated through detailed drawings. Henceforth after the choice of a definite concept, but before making detailed drawings I must first make a model.

Because the necessary materials were not in stock, the definite scale model does not correspond completely with my intended picture of it. In the future I must investigate if the relevant materials are in stock.

Next time I will start early on with thinking about and reflecting upon ideas; I ought to take into account my limited drawing talent. In this way I avoid working at high pressure; through that I am seized by panic. As soon as I realise that there is a lot of work to do while time is limited, I'm afraid to fail; and just the feeling let me fail.

After finishing the model I designed certain details afterwards. Only through a model I realised what I was forgotten. When it's possible to elaborate the design for a longer period, you can detail it continually better. Nevertheless, I must begin earlier with detailing.

I learnt that it is important to reflect on the way connections between elements can be made: are they visible? Did you let some room for the glue?

Next time I first begin with searching the most suitable materials; eventually I make a test model.

1.3
Process knowledge, declarative
If you follow a systematic design approach then your work will be more efficient. You can develop such a system through training and experience. Hence I must continually study.

I learnt that a substantial part of the information cannot be gathered only from books and magazines. I learn from people who are somehow involved in the product use. Observing previous designs is also very stimulating.

In the future I don't want to use the "process tree" (a requirements generating tool, hc) duty bound. My aim will be to use it for real generation of requirements. I think that the element 'product use' is not enough detailed. The rest is of secondary importance.

If you want to get a good list of requirements it's important to analyse the problem extensively. It's necessary to define the problem accurately, and to draft process trees which automatically lead to such a list.

2.3
Process knowledge, procedural
Firstly, I learnt how to develop a "process tree" and the meaning of it. The draft took much time; but making the list of requirements proved to be worth while. I was better able to generate this list, which had a more logical structure now.

I learnt how to make a choice from a number of different concept-solutions. Therefor, one must test each solution on the basis of the list of requirements. The best way to do this is to use a kind of table, because then one gets a good overview of the advantages and disadvantages of the concept solutions. Through this test one can make a choice.

When you design you must generate several concepts. In generating concepts you must try to forget the old ones. Otherwise the forms of the previous concept will unconsciously come back. In that case it's not a new concept but an adjustment of the previous one.

Data gathering (e.g. viewing height, width of a wheel-chair etc.) and storing is very important. The gathering can be used in the design process. The stored data can be useful later on in writing the technical report. Use a card-tray, or better a data-base, with the most important data.

3.3
Process knowledge, situational
In order to avoid mistakes I must use the list of requirements, also during detailing the concept (next time I must make a more extensive list).

Designing a three-dimensional test-model gives an useful spatial image of what you want to achieve. Through such a model you also can find many solutions.

I observed that the list of requirements must be made carefully, by prefer classified in groups. Through here you have a better overview when using an assessment system.

4.3
Process knowledge, strategic
I didn't present enough details regarding the construction of the chosen concept. Perhaps that causes problems because afterwards the concept may be worse when it tested on the basis of the list of requirements. Next time, before I choose the concept, I will make a more extensive description of the details.

Initially we didn't describe the problem, but we began with the "process tree" and the list of requirements. However, the problem definition must be used in defining the other things. Next time we can better start with the problem definition; that's the way to do it. Next, we continue with generating the process tree and the list of requirements.

Before you make concept proposals you must insert a short sketching phase; but of course you must plan your time. This way leads to results, although you are not 100% satisfied.

Don't plan too little time for the idea-generation phase, because in general the better ideas come later in time.

Late in the process you realise that you don't have all the necessary data, which you ought to gather during the information phase. I think that it will help after finishing the "process tree" to consider what information is missing.

Appendix IV

Table A.IV.1 Agreement in knowledge categories between judge 1(psychologist) and 3(design teacher); learner reports from the second half of design project 1B (see chapter 3)

1B2	Judge 2												
judge 1	1.1	2.1	3.1	4.1	1.2	2.2	3.2	4.2	1.3	2.3	3.3	4.3	4.3
1.1	34	11	3	-	37	2	1	6	7	1	-	1	103
2.1	2	9	-	-	3	2	3	-	1	-	-	-	20
3.1	2	4	-	-	-	1	-	-	-	-	-	-	7
4.1	1	1	-	-	2	1	-	3	-	-	-	1	9
1.2	6	2	2	-	31	5	9	3	8	2	-	-	68
2.2	-	3	-	-	1	8	1	2	2	2	-	-	19
3.2	-	1	1	-	2	1	10	-	1	-	1	-	17
4.2	-	-	-	-	1	1	-	9	3	-	-	-	14
1.3	5	1	-	-	14	1	1	8	22	4	-	2	58
2.3	-	-	-	-	1	-	-	1	1	1	-	1	5
3.3	-	-	-	-	-	-	-	-	1	-	-	-	1
4.3	-	-	-	-	1	-	-	3	2	-	-	3	9
4.3	50	32	6	-	93	22	25	35	48	10	1	8	330

Appendix Va

Information cards available during the design session (see chapter 4)

C. Technical aspects
- **C.1** Production
  - **C.1.1** Production techniques vs. costs
  - **C.1.2** Lathe
  - **C.1.3** Milling-machine
  - **C.1.4** Die set-up
  - **C.1.5** Die mould
  - **C.1.6** Design for assembly
- **C.2** Tension and rigidity
  - **C.2.1** Angular rotation and retardation
  - **C.2.2** Snap-connections
  - **C.2.3** Break
  - **C.2.4** Tensile and bending stress
  - **C.2.5** Torque: rigidity and maximum tension
  - **C.2.6** Torque stress: formulas cross-sections
  - **C.2.7** Moments of inertia
  - **C.2.8** Elongation
  - **C.2.9** Friction

E. Ergonomics
- **E.1** Operating forces
- **E.2** Compatibility
- **E.3** DINED I (anthropometric data)
- **E.4** DINED II (")
- **E.5** Pushing and pulling forces
- **E.6** Compensation factors to clothing
- **E.7** Body strength and age
- **E.8** Pedal forces
- **E.9** Reaching
- **E.10** Maximum lifting and carrying capacity
- **E.11** Lifting

K. Costs
- **K.1** Production techniques vs. costs
- **K.2** Costs computation model
- **K.3** Injection moulding costs: the mould
- **K.4** Vacuum moulding costs: the mould
- **K.5** Injection moulding: costs per hour
- **K.6** Vacuum moulding costs per hour

M. Materials
- **M.1** General properties
- **M.2** Plastics
  - **M.2.1** Chemical resistancy
  - **M.2.2** E (bending)
  - **M.2.3** E (pulling)
  - **M.2.4** Properties
  - **M.2.5** Maximum temperature
  - **M.2.6** Subassemblies
  - **M.2.7** Rules for designing in plastics (2x)
  - **M.2.8** Mechanical properties
  - **M.2.9** Costs / kilogram
  - **M.2.10** Strength (bending load)
  - **M.2.11** Strength (pulling load)
  - **M.2.12** Processing techniques
  - **M.2.13** Heat resistancy

Continued

Information cards - continued

S. Environment
- **S.1** Requirements
  - **S.1.1** Requirements Dutch Railways (NS)
  - **S.1.2** Analytic technique of product use (2x)
- **S.2** User trial
  - **S.2.1** Passengers
  - **S.2.2** Cleaners
  - **S.2.3** Content of the bins
- **S.3** Client
  - **S.3.1** Producer (Kouwenhoven)
  - **S.3.2** Dutch Railways (NS, VanDalen)
- **S.4** Train situation
  - **S.4.1** Sizes current train interior (2x)
  - **S.4.2** Wall construction current trains
  - **S.4.3** Sketches for new train interior (2x)
  - **S.4.4** SM 90: the new local train

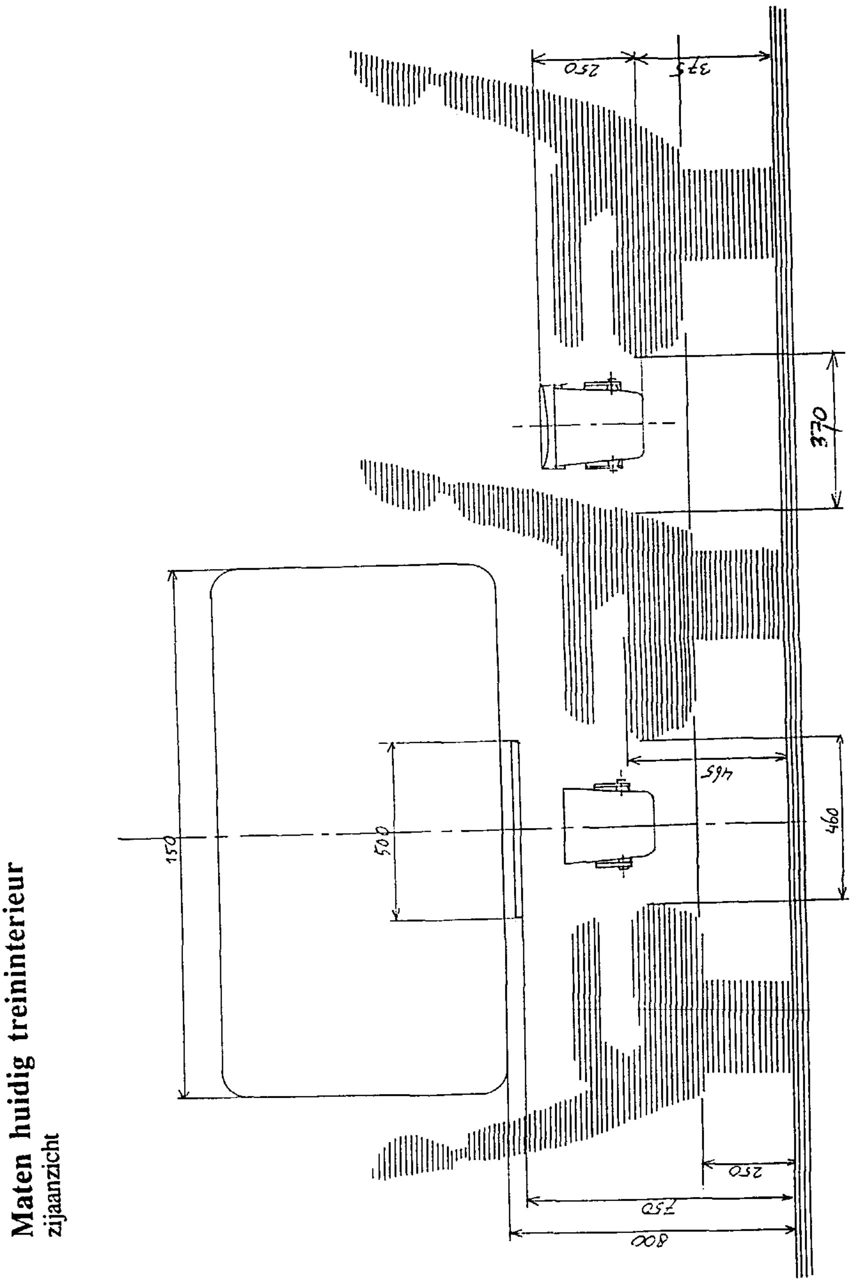
P. Product information
- **P.1** Existing NS-refuse bins
  - **P.1.1** Exploded view
  - **P.1.2** Turn-over movement
  - **P.1.3** Technical drawings (3x)
- **P.2** Design for new refuse bin NS (3x)
- **P.3** Examples of litter bins (15x)
  - **P.3.1**
  - **P.3.2** Brandvrij
  - **P.3.3** Pedaalemmer
  - **P.3.4** Plastic
  - **P.3.5** Staal
- **P.4** Emptying the bin
  - **P.4.1** Emptying tool
  - **P.4.2** Emptying: the procedure

S. Hinges (6x)

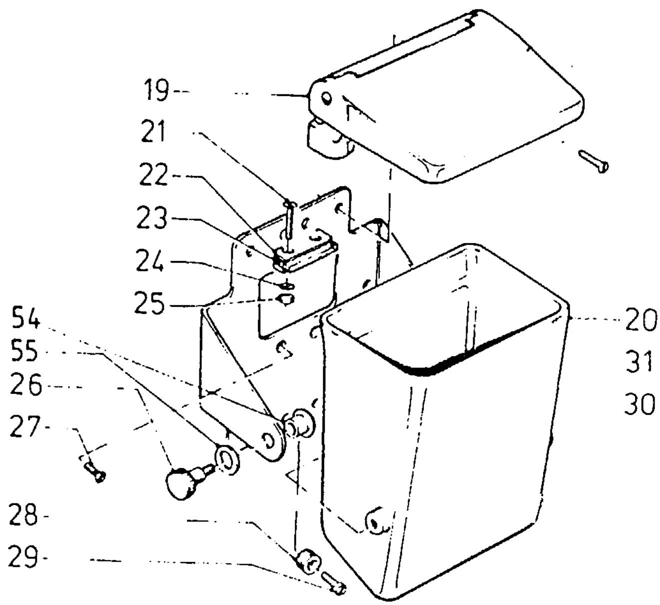
V. Vandalism

Appendix Vb

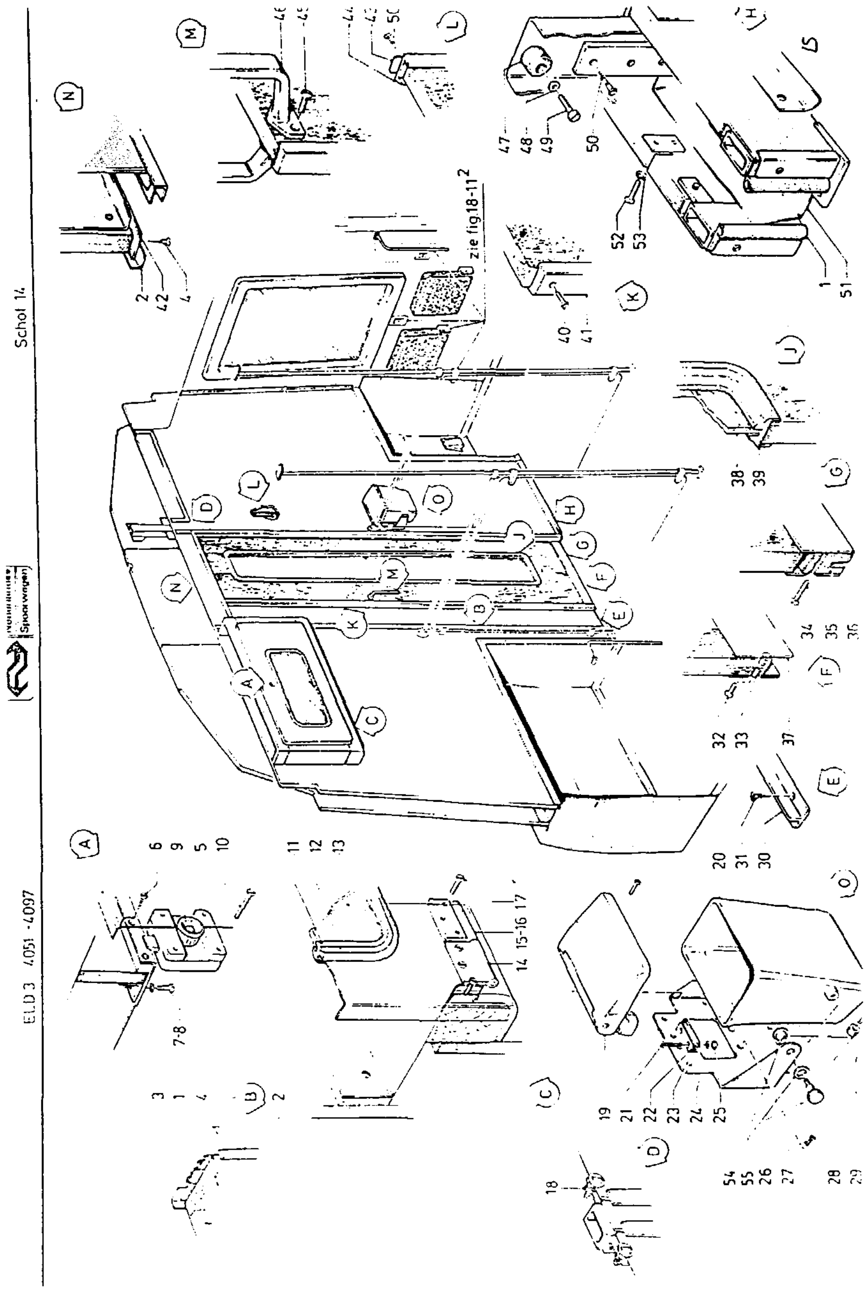
Examples of information cards available during the design session (see chapter 4)



Huidige afvalbak
(exploded view)



Wandopbouw huidige treinen



Appendix VI

Table A.V.1 Average intercorrelations among attributes in assessing designs from subjects in the protocol study (chapter 4)

Telephone booth	Crea.	Attrac.	Techn	Usabil.	Econ.	Overall
Creativity	-					
Attractiveness	.62	-				
Technical quality	-.25	.08	-			
Usability	.40	.53	.30	-		
Economic value	-.32	.30	.65	.41	-	
Overall value	.57	.89	.11	.79	.44	-

Appendix VII

Six one-hour 'thinking aloud' protocols

- Protocols can be read from left (column 'strategy') to right (column 'ideas')

- Abbreviations:

Q = question by the subject
A = answer by the experimenter

(w) = subject writes what he says

(number) = refers to a drawing (presented after the text)

- In column 'constraints':

g = given
d = derived
i = introduced

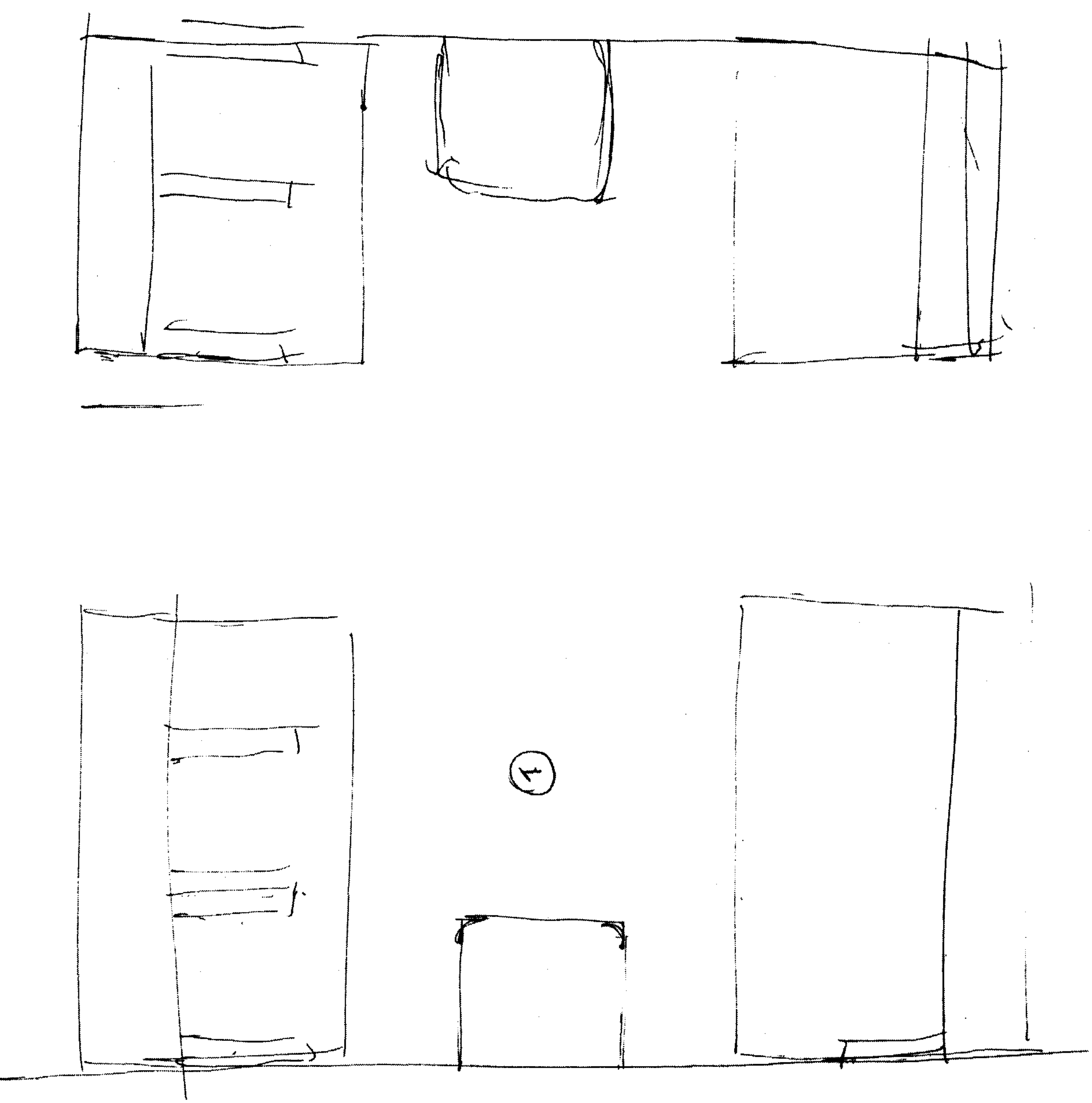
- A horizontal line marks a 30 minutes period in the protocol

Time	Strategy	Product elements	Constraints		Ideas
		(Reads brief)			
		New train (SM90) with extra seat			
		Can wider trains still pass each other?			
		I understand there is a emptying tool			
3		The NS conducted a survey study as to:			
		-the kind of waste			
		-the opinions of passengers, and			
		-the opinions of cleaners			
		Refuse system train SM90			
		Q: How is the location of the seats?	(A: 2+3)	g	
5		What is wrong with the existing system?			
		Has is to do with the location of seats?			
		Q: Location in present train?	(A: 2+2)	g	
		Q: Are all seats opposite to each other?			
		(A: Part of them)			
7	I start making notes of relevant things				
	I will ask for the survey study	The current functioning of the system			
	From present functioning can be derived				
	what is wrong and what can be improved	(Reads brief)			
8		Q: How is the redesign looks like?			
		(A: P2)			
		Q: Information on 3 survey studies?			
		(A: S.2)			
11			Some of the waste get stuck	d	
			Functions the same as current bin	d	
		Q:Do you have a sketch of the current bin?			
		(A: Exploded view: P1.1)			
12	Evaluation by the user is important for me	Opinions of cleaners	Dirty lid	g	
		Oh yes, it has a lid	Too small, 48%	g	
14	I will make new notes of opinions		32%: dirty	g	
			28%: dirty lid	g	
			22%: without easy reach	g	
16	I set aside opinions cleaners	Refuse system and cleaning system	..are 2 independent systems	i	
	I start with the refuse system	Volume of the bin	40% newspapers	g	
18					Separate newspaper bin
		That idea will appeal to people			
		Is solution for problem of too small volume			
		I know enough about current bin			
		Redesign bin from NS (takes info card P2)			
		The low enthusiasm is understandable			
		Q: More information on evaluation redesign?			
		(A: no)			
		Q: Volume current bin?			
		(A: Technical drawings: P1.2)	Size is equal to current bin: 20x25	d	
21		Opinion current bin	Too small	g	
			Dirty	g	
			Dirty lid	g	
			Hygiene is relevant	g	
			Difficult reach	g	
23		Redesign NS (takes P2)	No lid: dirty	d	

			Too small because of equal size	d	
			Without easy reach	d	
25		Q:Redesign at the same location?	(A: Yes)	g	
		Q:Lay-out new train?			
		(A: Not yet defined; still open)			
	First I only generate principle solutions				
	It's nice to start now with idea generating	Train with new location seats(sketches 1)			
		The back of the seat (1)			
		Path in the middle (1)			
		Elbow-rest fixed to the wall (1)			
		Window (1)			
		Table (1)	You bumps your knees on it	i	
		With rounded edges	Three seats in a row (1)	g	
			That will be rather narrow	d	
27		With a path in the middle			
		Q: How will they fix that?			
		(A: The width increases with 30 cm)			
		(takes measures of his chair)			
		Here is the gangway			
		How about the location of the seats?			
		Like an aircraft			
		Here a narrow block with 2 seats (1)			
		Back of the seat (1)			
		Elbow-rests (1)			
		Table (1)			
		Under the table the bin is located			
29		Q: A lay-out of the current train?			
		(A: Side-views interior: S.4.1)			
	I'm looking for a location		Existing bin is rather small	d	
30					
		How is the behaviour of the passenger?	He doesn't want to leave his seat	i	
			Thus, bin within easy reach	d	Towards the outside is a possibility
		Q: Lay-out train still open?			
		(A: Yes)			
		Current system is rather primitive			
		Analogous refuse system			The new public lavatories
					..cleaned automatically
		(Consults sketch design new train)			
		Not very detailed			
32	I intend to change whole system	Current bins:	Not easy to cleaners	d	
			Cleaning procedure has to be changed	d	
		Current bin	Possible to turn-over	g	
			With or without a lid	g	
			Dirty	g	
			Difficult reach	g	
34		Possible solutions:			Enlarging the bin
					An automatic lid
					A refuse sack hanging out the window
					...thus emptying from outside
					A grinder because of small room
					...with central transport
					Tube system through the train
					A way of intensive cleaning:

					...throw all waste on the floor A 'self-cleaner': ...waste moves to both sides
38	I learned to gather information endlessly, approaching everything methodically. However, the more you postpone your ideas, the more you will be blocked. So I choose the following strategy: Generate ideas in an early phase, record ideas as soon as possible because: (1)you create more room for new information (2)you avoid simply forgetting an idea				
40	I didn't bother about the client's wishes I give priority to the wishes of NS It's half past 2, so 2 hours are left Let's read the brief again	(Reads brief) The client manufactures bins and buckets Maybe they can't produce it	So they want bins again	d	
46	Difficult to decide without consultation	"Tomorrow you have a meeting.." (A: Consultation is possible) (Reads own ideas)			Kind of tube towards the side or outside Kind of refuse bin with a shoot only Inside a kind of lid on this shoot
		Selection of an idea implies: In what phase is development of the train?	I have to adjust the train	d	
49	Let's read the brief again	(reads brief) Deliberation between client and NS manager Q:Can I interview the NS project manager? (A: Written interview: S.3.2) Q: Do you have sketches of new interior? (A: Sketches: S.4.3) Current bin is Fl. 160,00 The weight of the bin is 5 kilogram That's incredible heavy (Reads survey study: S.2.2) Cleaning procedure is very labour-intensive (Looks at sketches carriage: S.4.3)	Possibility to integrate bin in wall	g	
52	In conceptual phase this idea is nice to use		Integration in the wall is possible	d	A tube system towards a separate location (no bins)
		Advantage: emptying mechanism outside train ..and thus, to automatize			Outside the shoot falls open, and waste comes out
55	This is important: NS takes the decision I have no expectations about this list I never conform me entirely to requirements A design does not arises suddenly from a list of requirements	in view of cost price of the current bin: (Reads information about train: S.4.4) (Reads interview with NS: S.3.2) Q: I want a list of requirements from NS?	A real investment is possible	d	
57	For a moment I will dwell on my ideas	(A: list of requirements NS: S.1) Indeed, the list doesn't contain anything (Reads interview with NS: S.3.2) Current solution is not relevant any more			Bigger bin with automatic lid

		(Evaluation idea)	Less room for legs (-)	d	
			Fits into the same system (+)	d	
			people are familiar with it (+)	d	
			Problem of cleaners is not solved (-)	d	A combination of emptying from outside, tube-idea, and grinder of waste
		(Evaluation idea)	Producible	d	
			with present pneumatic pressure	i	
		Advantage bigger bin:	More volume	d	
60					



Time	Strategy	Product elements	Constraints		Ideas
		(Reads brief)			
1		(Views the NS-brochure)			
		Let's look how train is designed			
		I expect something about the interior			
		The inside of the train is not in it			
	I start thinking it over				
	About solutions	Which requirements must be met?			
3	I begin with writing down				
	'inside' information	The refuse bin turns(w)			
		Located on feet level(w)			
		Underneath a table(w)			
		SM90	Important: 3 people in a row(w)	g	
4		Refuse bin	Within easy reach(w)	i	
			Capacity should increase(w)	i	
			It wears well without much maintenance	i	
			A plastic system is simple	i	
5		What's wrong with current bins:(w)	On a unpleasant location(w)	i	
			Difficult to reach(w)	i	
			Sometimes you stub your legs(w)	i	
			It has no lid(w)	i	
			Capacity is too small(w)	i	
			Intensive use doesn't occur(w)	i	
			Practical flipping system(w)	i	
			Easy to clear out(w)	i	
8		Location in new train	Bin on more obvious, visible location(w)	i	
		Styling of the bin	Form and colour are more important(w)	i	
9		Refuse bin: with what to combine(w)			With the ash-tray(w)
					With table(w)
					In the wall(w)
					In arms of the seat(w)
					In chair-leg(w)
					Or perhaps in floor(w)
		(Bin)	Priority to height and attainability(w)	i	
10		Refuse bin and emptying tool(w)			
		Handing to keep bin at the same place			Thus with separate holder
	Let me summarize	Design:	Proof against improper use	i	
			against vandalism etc.	i	
12		Requirements for manufacturing			
		Requirements for use			
13		Requirements for styling			
		What does appeal?			
	Let me arrange the requirements				
14		Q: What is the lot size?	(A:5600 a year, for 10 years)	g	
		Manufacturing(w)	Lot size, 10 years: at least 50.000(w)	d	
15		Production method	Roto-moulding is easy	d	
			but expensive	i	
			With small vacuum moulding	i	
			Roto-moulding will be preferred(w)	i	
			Model must be relievable(w)	i	
		What else is important to manufacturing?			

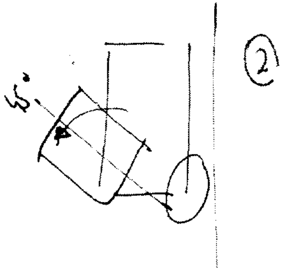
16		Estimation of costs(w)	It must compete with current bin	i	
		Q: Do you have data about costs?	(A:ƒ 160.00/bin)	g	
		(Material bin)	New bin must be made of plastic(w)	d	
17		Costs	Estimated: ≤ ƒ 90/100.=(w)	d	
		Minimum sizes are known			
		Q: Capacity of current bin?			
		(A: info card P.1.3)			
18		(measures)			
19		230 x 210 x 110	About 5,3 litre	d	
		New bin	Somewhat larger capacity	i	
21			Minimum capacity: 5,5 - 6 litre(w)	i	
		Manufacturing	New with current production methods	d	
			Not boarding out	d	
			Not purchasing	d	
22		Use is very important	It must be easy to clean:(w)	d	
			In practice with one hand(w)	i	
			It must be possible to lock(w)	i	
			Cleaners need not stoop too much	i	
			Putting down waste must be possible	i	
			with one hand	i	
			preferably at an attainable place(w)	i	
			Wherever one is seated	i	
			The refuse bin must be located central(w)	i	
			Bin must not be placed on feet level(w)	i	
			About 10 cm from the floor(w)	i	
24		Q: Do you know measures of the window?			
		(A:Not known for the new train: S.4.1)			
25		Bin	Front view <30 cm(w)	g	
			Above knee level(w)	g	
			Underneath the window level(w)	g	
26		Many people put newspapers in the bin	It's important that it fits	d	
			Without coming out	d	
			Somewhat folded	d	
			Newspaper'format is A1,...A2	d	
			Newspaper(A2) must fit when	d	
			folded 2 - 3 times(w)	d	
			Without sticking out	d	
27		Bin	Bin replaceable separately(w)	i	
			apart from the holder	i	
		Special material features			
28		Styling bin	Styling integrated in interior	i	
			It must not attract attention	i	
			Not to fit in as a separate bin	i	
			Detachable bin leads to destruction(w)	i	
			Colour: indicate that it's a refuse bin(w)	i	
30					
		Material is important	It must be chemically resistant(w)	i	
			It may not give a poor impression(w)	i	
			It must be scratch-proof(w)	i	
			Colour-proof(w)	i	
			And important: hit-proof(w)	i	
			without breaking with the first kick	i	
			Chemically resistant	i	

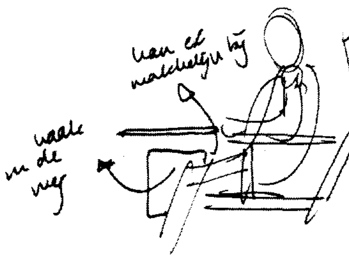
		Rather high temperatures occur	usable with temperatures till 70• C.(w)	i	
			It must be roto-moulded	d	
32		Invulnerable place	A clearly protruding bin	i	
33		Current system looks like that			
		Flipping mechanism			More practical: drop it to the
					inside of the wall(1)
34		Basic solution	Current system as an indication(2)	d	
			Bin hangs straight	g	
			Maximum degree of 45(2)	i	
		A rather vulnerable place			
35		A system would be nice that:(3)	Can also flip	i	
			Under which you can hang something	i	
			Flips to the inside(3)	i	
		Styling			Integrated in the wall
					Which comes closer to you
37		Q:Is the aim only one bin?			
		(A:There are no constraints here)			
38		Location bin	I first start from a central bin(w)	i	
			For each row of 4 - 6 persons(w)	i	
			Then it location must be window side	i	
		Window side(4)			
		Side of the seats(4)	Flipping upwards,	i	
			to the left and the right(4)	i	
			This comes close under the table	i	
40		There are some difficult problems	4 people on a row(w)	d	
			Current location maintaining(w)	d	
41		Refuse bin(5)			On the left or right side above
					the seats, that's better(5)
					You can fix it to the luggage-rack(5)
					Movable to the left and the right(5)
42		Compartment(5)			
		Bin movable to the right(5)			
		At the level of your head(5)			
		Usable on both sides(5)			
43		The basic solution:	6 seats, 3 in a row	g	
			Not on knee level	i	
	Let's guess about the sizes				
	It's a good idea to sketch it	Window(6)			
		Here the table(6)			
45		3 seats in a row(6)			Here comes a rail at the right level(6)
					On this the bin can ride to and fro(6)
					Easy to empty at the bottom(6)
		Here you have the rack(6)			
47		There are of course disadvantages			
		It's indeed usable on both sides			
		After all it is practical			
		Maybe it's too big			
		But it makes the movement possible			
		Difficult			
49		Distance between opposite seats(w)	Relatively small(w)	g	
			Difficult to locate a refuse system(w)	d	
50		Another solution			You can make a bag of it
		Basic solution with 4 in a row:			Choose something that is integrated
					in the wall

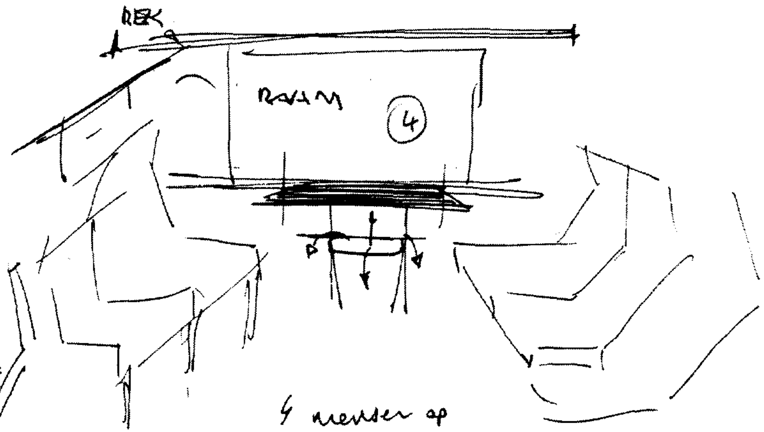
51		That's rather difficult		You can think of the ceiling
		That's exaggerated		
		Location of the bin(7)		In the middle of the seat(7)
				Here at the top to and fro
				Behind their heads
		(sketches side-view)(8)		
53		Upper side(8)		Bin can move
				Emptying at the end of the seat
				Emptying along the gangway(w)
				At the right level:No useless stooping
		Difficult to reach		
		(sketches bin)(9)		With openings on side and upper side(9)
				Refuse bin with to entries(9)
55		Form bin(9)		Two passages(9)
		It is placed here(9)		
		Opening here/similar to the back-side(9)		
56		Waste can be thrown in on both sides		
		A shoving system		A rail(w)
		How to empty		
		Somewhat difficult		
		It can be done on both sides		
57		How should you do it?		
		How to empty it?		Make a flap, e.g. with a spring
				Flipping
		What kind of emptying system?		
		There are different ways		A flap
		That's a vulnerable point(w)		
58		Question: the running system(w)		Rail(w)
		Emptying system(10)		
59		Here the rail(10)		
		The bin on it(10)		
60				

PRINCIPE OPLOSSING

bestaand systeem als indicatie







1e lijnen bij een centraal systeem
1 afvalbak per stoelenrij → 4 - 6 personen

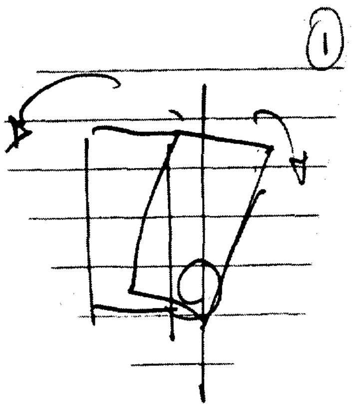
goed systeem = kantelsysteem

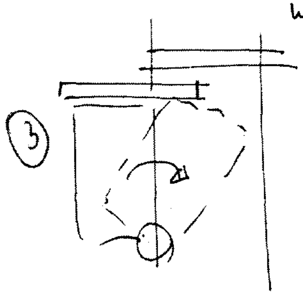
↓

kantelsysteem naar binnen

↓

verzamelen in de wand.



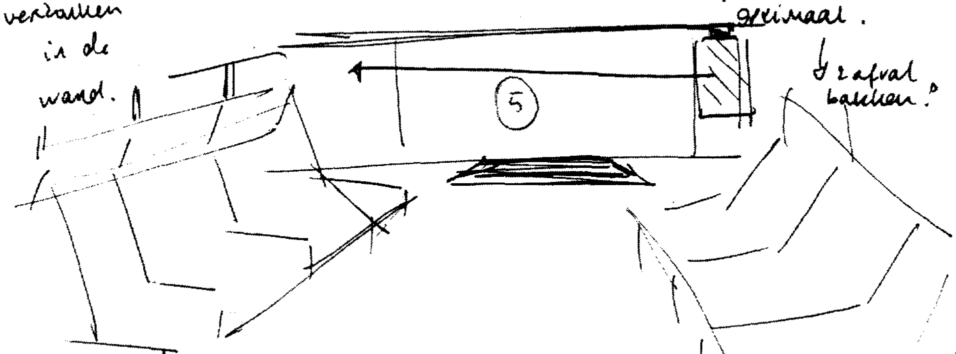


→ moet dan wel aan de raamkant.

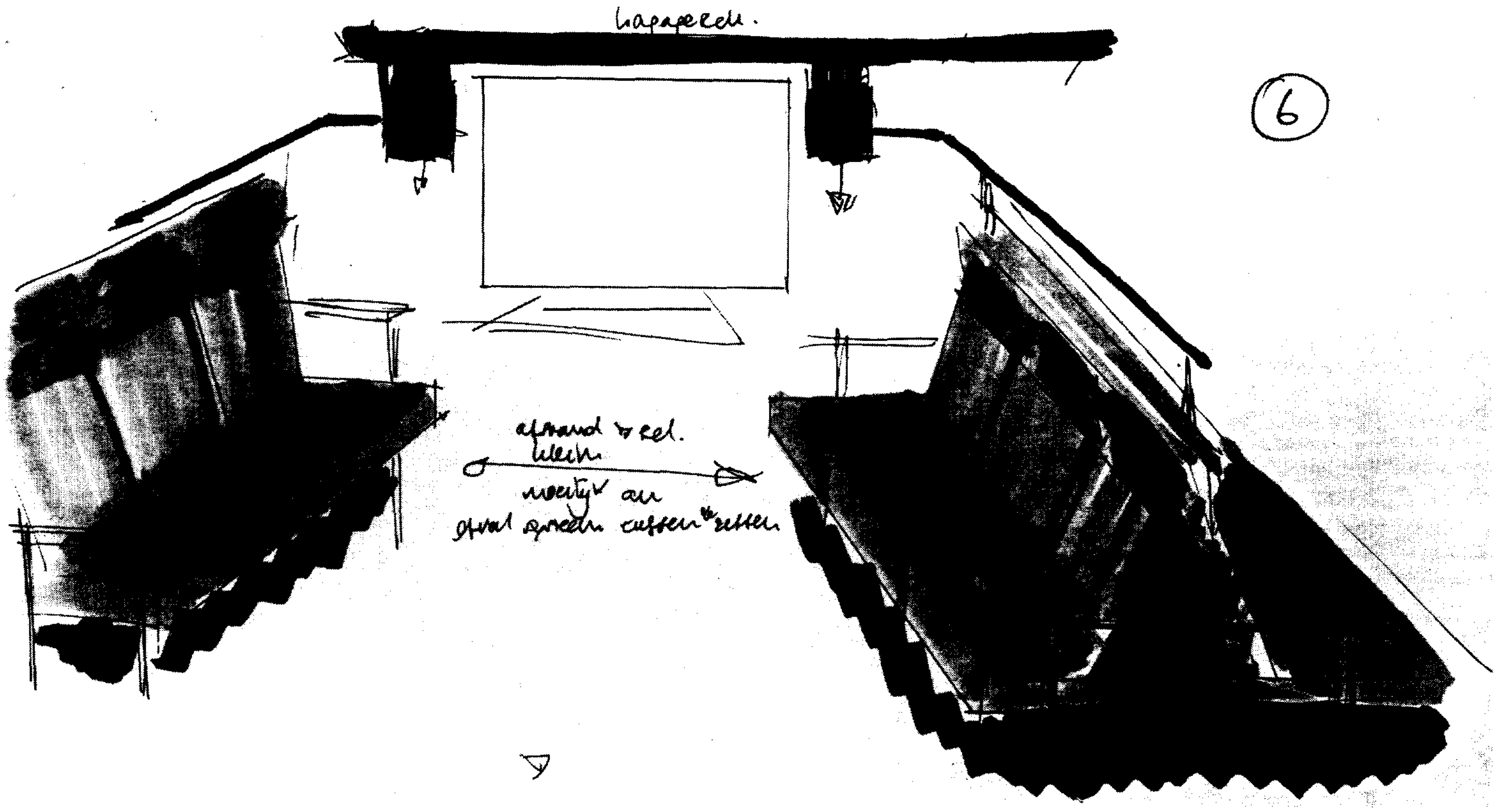
4 mensen op een rij → plaats zoals nu handhaven

6 mensen → plaats niet meer optimaal.

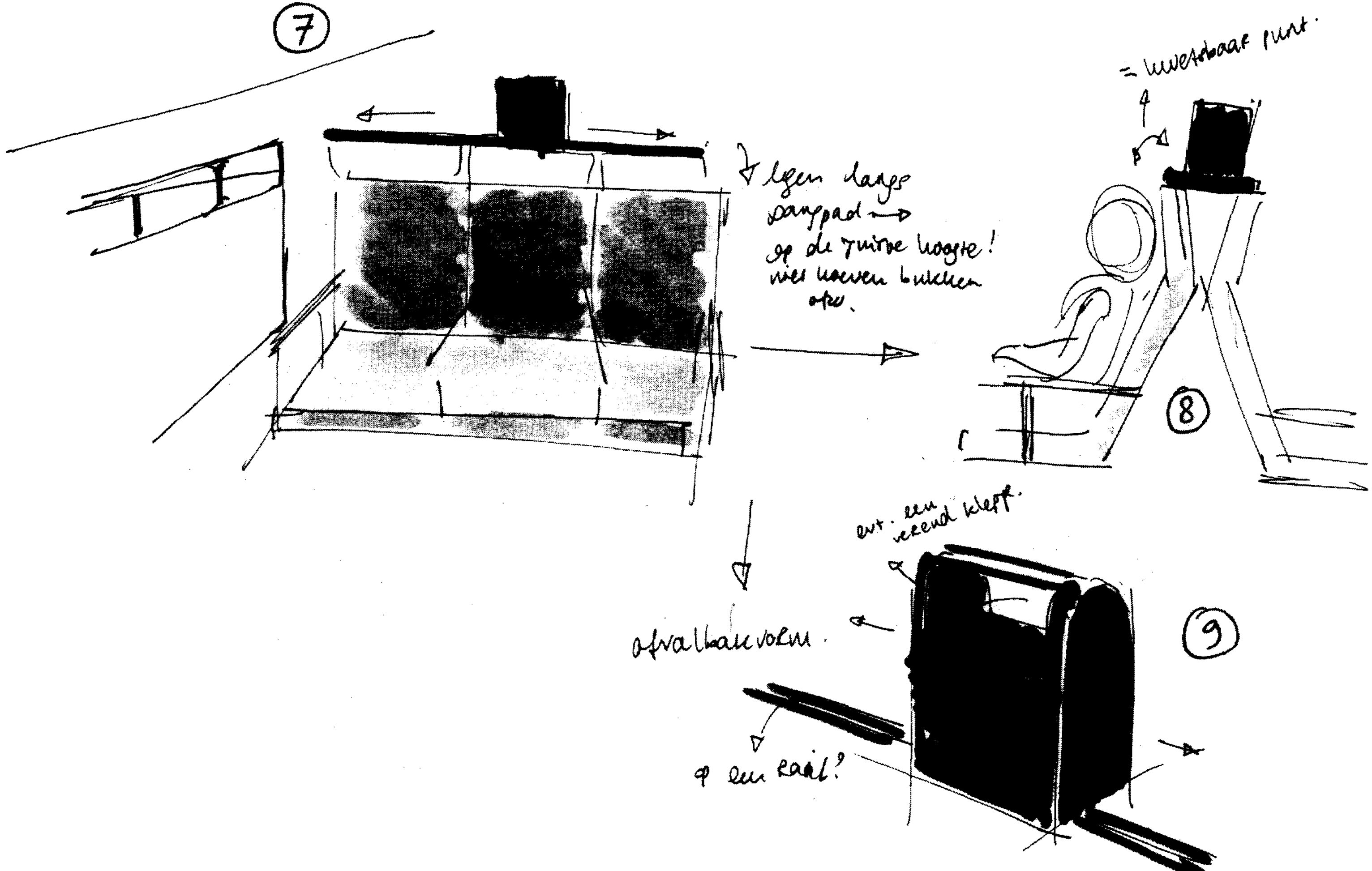
↓ 2 afval bakken?



1) PRINCIPE OPLOSSING AFVALBAK 6 STOELENRIJ



uitgaande van principeopl. 1)



Time	Strategy	Product elements	Constraints		Ideas
		(Reads brief)			
		Q:What is roto-moulding?			
		(A:Technique is explained)			
		Q:Does it centrifuges?	(A:No, it is smashed all sides)	g	
		Q:Does it coagulate and ready?	(A:It coagulates slowly)	g	
		Q:It must be loose?			
		Q:Is an arch allowed?	(A:It must be loose)	g	
2		(Reads brief)			
3		Estimation of costs			
	I look first to the bin	The volume of the bin			
	I underline what is interesting	(Reads brief)			
4		The bin	Must look flash and modern (w)	d	
		Train is also new			
		How is the train looks like?	Fifties' look is not wanted	i	
		Lemmens' chance to profile			
		(Bin)	Must attract attention	d	
		Refuse			
		Kinds of refuse			
		Coffee cups (w)			
		Sweet slips (w)			
		Chewing gum	Nasty, it won't stick	d	
		(Bin)	Must be easy to reach	i	
		Coffee cups			
		Opening bin	May not be too small	d	
		Other kinds of waste?			
		Old newspapers? No			
		Handkerchiefs...			
6	I cannot think out more	Bins + emptying tool (w)			
		That's a scoop or the like			
	I start sketching				
	Let me see the brochure first				
	Perhaps it contains something useful	(Brochure NS)			
		Q:Is the SM90 in it?			
		(A:Yes)			
		Local train for the nineties			
		Gives not much information			
		No technical data either			
	I don't think it's useful	Maybe the outside of the SM90			
		Somewhat dull styling			
		Somewhat aerodynamic			
		Abortive TGV, as it seems			
		Slow version of it	Clever: bin with same styling	i	
9		Front of slow TGV aerodynamic (w)			
		Somewhat slack (w)			
		Looks like a stopping train			
		Like super fast ..(train)	He must be flash and modern (w)	i	
			Attract attention	i	
		Nearly every carriage			
		Requirements bin	Opening not too small	d	
			It must be within easy reach	d	

			Somewhat in same styling of train	i	
			It has to be producible	d	
			Either by vacuum form (w)	d	
		(Reads brief)			
		Oh,..the bin	No vacuum form	d	
			preferably injection moulding	g	
			Either vacuum form or injection moulding	g	
			Thus injection moulding must be possible	g	
	Where am I?				
11	(Numbers requirements written)	Don't forget the emptying tool			
		Aerodynamic refuse bin			
		Injection moulding comes later on			
		Do I invent a new system? No			
		How is the old system?			
	I try to sketch it	Old system as I remember..			
		Bin which is emptied (1)			
		With lid (1)			
12		Turning-point (1)			
		Lid (1)			
		Emptied (1)			
		Q:But what is wrong to the system?			
		I will ask the NS			
		Q:Info on the interior of train?			
		Q:Interior of the SM90?	(A:Interior SM90 is not yet designed)	g	
		Q:And the interior of the old one?			
		(A:Info card S.4.1)			
14		Q:What are the disadvantages of the system?			
		Q:Info about the opinion of the cleaners?			
		(A:Info card S.2.2)			
	I forgot the information in the brief	(Reads card S.2.2)			
		Working long hours on trains			
15		Working in the dark			
		Q:Is the ash-tray involved?	(A:No)	g	
		Liquid			
16			It must be waterproof(w)	d	
			To be emptied on a high location (w)	d	
		(Reads) Director			
		Waste disposal bags	Too wide	g	
		Q:Sizes of disposal bags?			
		Maybe there are other			
		Or the gangway is too small	(A:There are all sizes of bags)	g	
			(A:Or it can be produced)	g	
	Fine,I can invent it myself	Waste is left about			
		What can you do against it?			
		There's only short time to empty the bin	Bins must be quickly to empty (w)	d	
		Stench .., that's a pity			
		Ride with containers:			
		Takes a lot of effort			
	I don't design a container		In emptying the bin,	d	
			it should not fall forward too early(w)	d	
18		Changing the bins while emptying			Perhaps connect a piece of string to it
		(Reads)Newspapers get stuck in emptying tool			
		So the emptying tool			
		Q:What is an emptying tool?			

19		(A:info card P.4.2)			
		Aha, it encloses the bin			
		Cleaning tool is thus a bag	Must be big enough for newspapers(w)	d	
		How big is that?			
		Is that when you fold up the newspaper?	A4, when you put it in?	d	
		Newspaper-story is not interesting(w)			
		Tool-opening	Same size as bin-opening(w)	i	
21		Bin	It must have a lid, I think	d	
			Without lid:big opening necessary	d	
			Which you can see at once	d	
			Else, one can put nothing in it	d	
		If it has a big opening	One sees all the waste	d	
			Unless it has a lid	d	
		Thus either a lid or a flap(w)			
		Bin wit lid(2)			Lid with spring that returns automatically
22		How do you empty such-like?			
		Problem is the emptying(w)			
		Advantages of lid	Is funny to throw something in it(w)	i	
			Throwing away is rewarded(w)	i	
			incentive to put waste in	i	
			Thus less waste on the racks (w)	d	
		Disadvantage flap	It breaks down sooner (w)	i	
23		(Emptying)			Emptying thing that pushes flap aside(3)
			It might have been worse	d	
24		Waste will go between wall and flap	Thus a flap will be nothing	d	
			Thus it will be a lid	d	
			Flap is out(w)	d	
	Let's sum up	Bin	I want a lid(w)	d	
			Big opening(w)	d	
			Waterproof	i	
		Plastic is waterproof, isn't it?			
25		Bin	Quickly to empty(w)	d	
			High(w)	i	
		So, this is the bin(w)			
		This is the emptying tool(w)	The opening of the same size(w)	d	
			It must be flash(w)	d	
			Modern(w)	d	
			Aerodynamic(w)	d	
			Attention attracting(w)	d	
		That's a lot for an ordinary refuse bin	Within easy reach	d	
	I start really sketching now				
26		(Reads) requirements refuse system			
		What requirement is important?	Within easy reach	d	
			Everything is important	d	
	I get stuck on a new system	Disadvantage old system	It flips too easy	g	
			I have to remedy the flipping	d	
		Connection of the bin	I'll locate the hinge-point elsewhere	i	
27		(Reads)Drawing old bin			
		Flipping			Or a kind of snap-system
					A catch
28		Now the hinge-point is here(4)			
		Hinge-point			I move it to top left
					Flipping is difficult now
29		But then it's the current bin again			

		Supposing here is the wall(5)			Supposing here is a rail
30		Litter bin(5)			
		When you empty it(5)	It goes upwards	d	
			While the hinge-point stays here	d	
		With emptying it takes this position(6)			
		Is that clever?			
		So that's a rail(w)			
		Hinge-point	It must be more flexible	i	
31		A tall bin	Bin cannot be emptied on higher point	d	
		Advantage of a high hinge(6)	It doesn't flip quickly(s)	d	
		How can I raise the bin?			
		Bin upwards	It's not nice	i	
			Then you look against it	d	
		Emptying			
		Emptying the litter bin higher/lower(w)	In use it must not on high	d	
		Is that feasible?	No, bin is under the table	d	
		Emptying tool	It must be designed principally	d	
		Bin	Emptying lower	d	
		(Looks at formulated requirements)			
33		Here is the litter bin(7)			
		Emptying tool(7)	It must fit in there	d	
	We'll see	(Looks at own text, p. 50)			
		Lid			
		That's not insurmountably			
34		A big opening either			
		That will work			
		Bin	Quick emptying	d	
		Thus it lies with the emptying tool(w)			
	Let's put it over there	Bin	It must also be high	d	
			or emptying low	d	
	That can wait		Flash/modern/aerodynamic/marked	i	
	It can wait	Bin	Must be easy to reach	d	
		Flipping			
		Thus that's the rail			
		Bin	Must be easy to reach	d	
			Yes, that's difficult	d	
		A lot of conflicting requirements			
35	What is important?	That the cleaners get back complaints			
		Or that chewing gum get stuck	But the bin cannot upwards	d	
	Let's first design a flash shape				
36		(Looks at the train brochure)			
		Side-view(8)	Get's the same shape as the train	i	
37		Here you put the wall(8)			
		Then the bottom must be here(8)	Otherwise you cannot clear it out	d	
		Is that clear?			
		Do you see that this is a train?			
		When you put head-lights here	It's too childish of course	d	
		Where is the hinge-point?			
		Hinge point(8)	That's impossible because of the table	d	
		Newspaper			
		New concept of the bin(9)			
39		It slopes (9)			

		The mess must put in(9)			
		To empty here(9)			
		Flipping is not necessary			
		Q:A section or technical drawing of interior?			
		Q:How are tables connected?			
		(A: info card S.3.1)			
		Q:What about the SM90?	(A: Not yet decided. It's up to you)	g	
		(Looks at S.3.1)			
40		Bin is indeed under table			
		There is also a window	Thus bin cannot upwards	d	
41		Stooping by cleaners is a problem	The emptying tool must be the cause	d	
		Wait, here is a lid and there is no one			
		How about that?			
	Wait a minute	(Refuse system)			Supposing throw everything in wall
					Central system, should be nice
					Kind of chute
					Throw everything outside at once
	It's worth a concept				
43		When you have here the train,			
		You have here litter bins			
		No, chutes			
		A central reservoir			
44		But does the waste drop?			I can use a big vacuum cleaner
		The idea is possible			In train wall(w)
					Here is the extractor, a door etc.
					Cleaners need only to go to the platform
					There they can clear out and go back
		That saves time			
45	Q:Ho many concepts are required?				
	Q:Or is it up to me?				
	(A:It's up to you)				
46		Risk: bin will look like the old one	They will not appreciate that	d	
			Must be new, not only the styling	d	
			Anyone agrees with that	d	
		But is that in bin or cleaning tool?			
		The bin can be designed more modern	But that's not enough	d	
		(Reads brief)			
47		I think an exchange is needed			
		Another possible concept(11)			That vacuum cleaner in train wall(11)
		In fact it' the same kind of idea(11)			And here you put in the waste(11)
					And here you couple the tube(11)
					Vacuum cleaner
			Must be very strong	i	
			Powerful vacuum cleaner(w)	d	
		It is possible			
		With connecting the tube			The lock opens(w)
		There is the lid again			
49		(Looks at the own requirements)			
		Lid or big hole, all is possible			
		Quickly to clear out?			
		Vacuum cleaner connected and ready	The idea to go upwards is not needed	d	
		The operation of the extractor tube(11)			Fasten a stick to the tube(11)
					With a handle(11)
		Then stooping is not necessary			

		Refuse system	Flash/modern/aerodynamic/marked	i	
		It strikes because you see nothing			
		Aerodynamic because you don't see it			
		It's modern for sure			
		Flash also			
		Refuse system	Must be easy to reach	d	
		That's the problem			
		It' not within easy reach	The problem of easy reach(w)	d	
		For the rest it meets the requirements			
		Lay-out of the train			
		Platform(12)			
		Doors(12)			
		Here you have the waste bins(12)			
		Q:Lay-out train-unit?			
		(Can be derived from the technical drawings?)			
51		(Looks at brochure NS)			
		Is the new one in it?			
		Q:Is the new onc not finished yet?			
		(A: info card S.4.4)			
		That's of no use to me either			
		(Reads S.4.4)			
52		(Reads brochure)			
		New litter bins(12)			
		Here a vacuum cleaner connection(12)			
		That's not clever	Vacuum cleaner must be taken away	i	Vacuum cleaner sticks to the container(w)
					It passes all bins
54		A refuse room (w at 11):disadvantage?	The wall must be adjusted(w)	i	
		(Reads brief)			
		Has nothing to do with my client			
		Through this design his employment is over	A bin is required	g	
55	Away with it	Can they make containers?	No	d	
56	It doesn't matter, go on				
	I'll write it	Bin	Must be vacuum moulded(w)	g	
	I'm not satisfied with that	The same bin(13)	That's no problem	d	
		Here is the table(13)			
57	Let's measure if it's possible	(Looks at drawing train)	That's possible	d	
			No	d	
		How much room do I have here	Thirty centimetres	g	
		Q:Are these the only drawings?			
		(A:I have drawings of the bin)			
	Please give me, it can be of help	(A:P.1.1:Exploded view)			
58	That's of no use to me				
	Let's take a chance				
59		Distance between table and floor	About 50 centimetres	d	
		Current bin is...			
		Q:Are the sizes mentioned?			
		(A:P.1.3; is more accurate)	That's half of it, it's ok	d	
			It's simply possible	d	
60					

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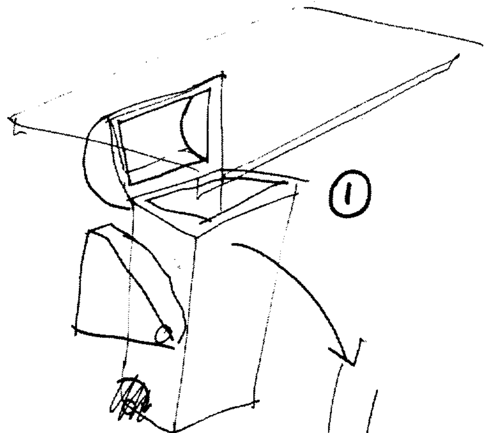

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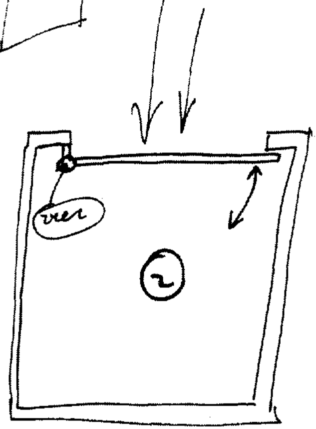
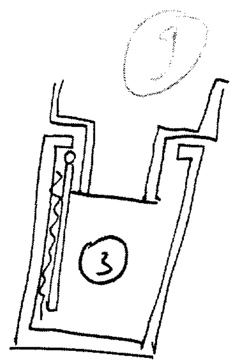
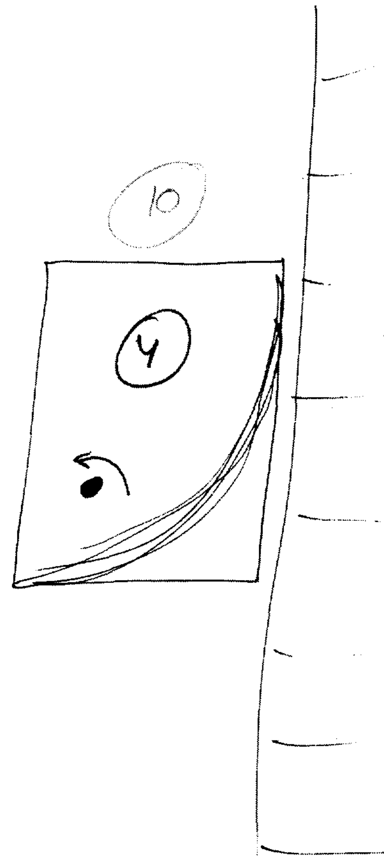


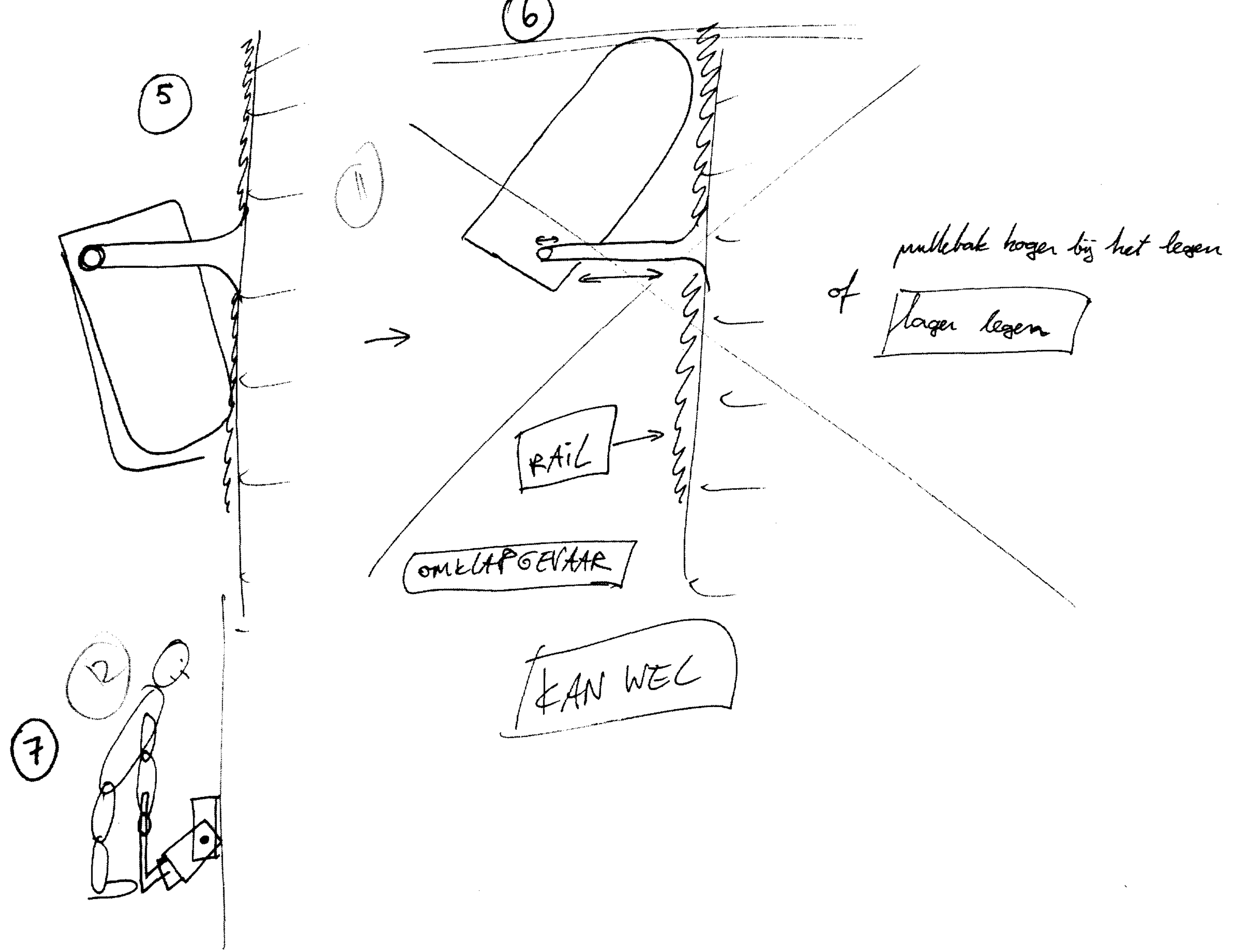
probleem: het legen

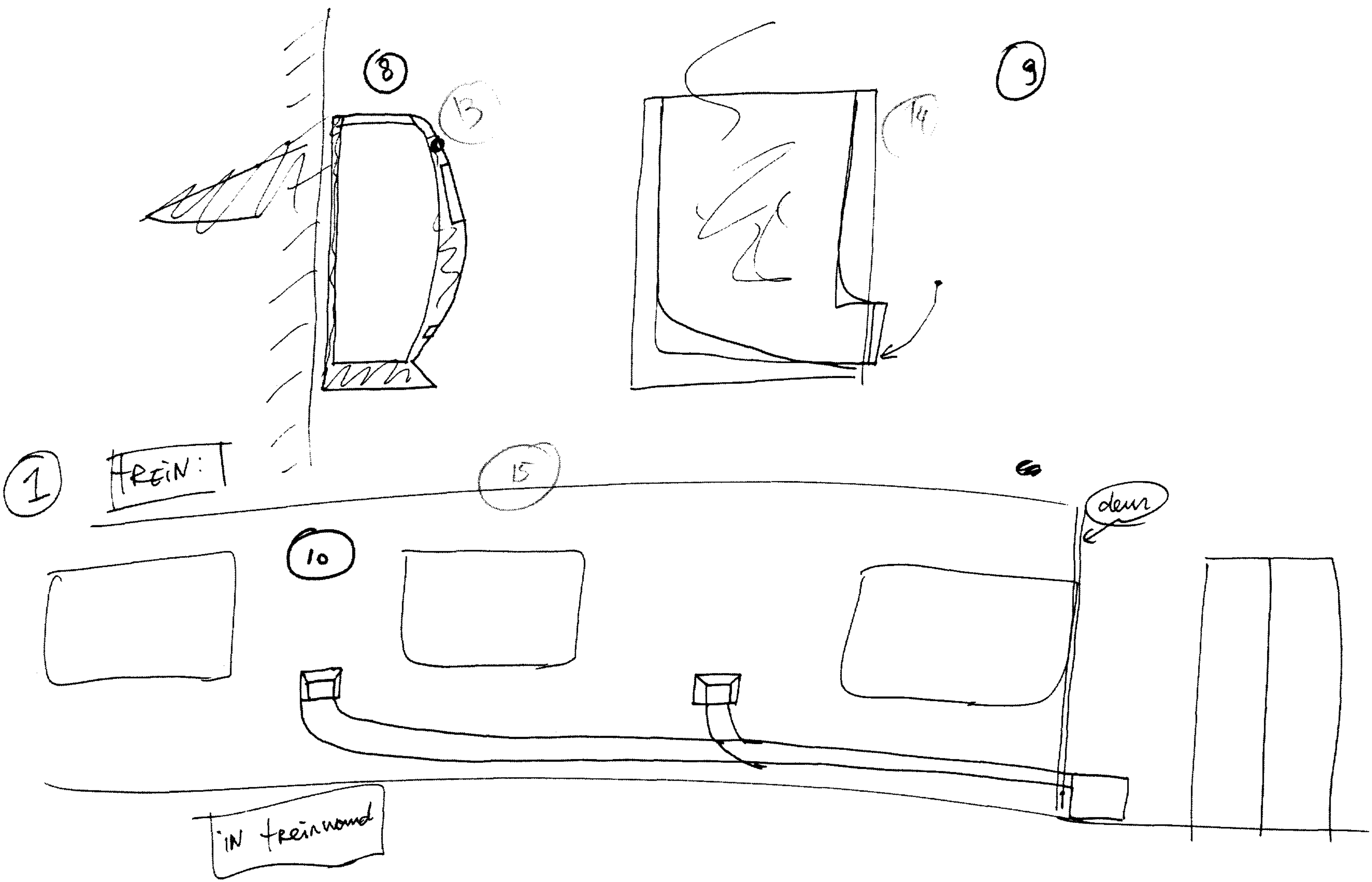




omklappen: sluiting/klik tegen omklappen

schanierpunt naar ↖ (1B).


5
6
7
pullebak hoger bij het legen
of
lager legen
RAIL
OMKLAPGEVAAR
KAN WEL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13
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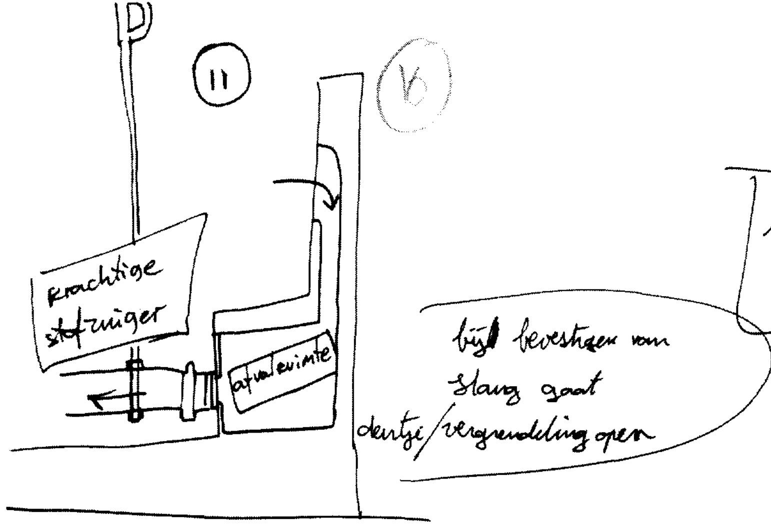


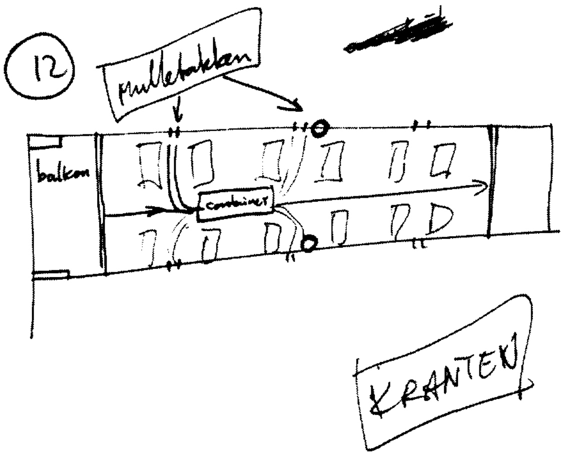
16

het probleem vh bijkunnen!

NADELEN:

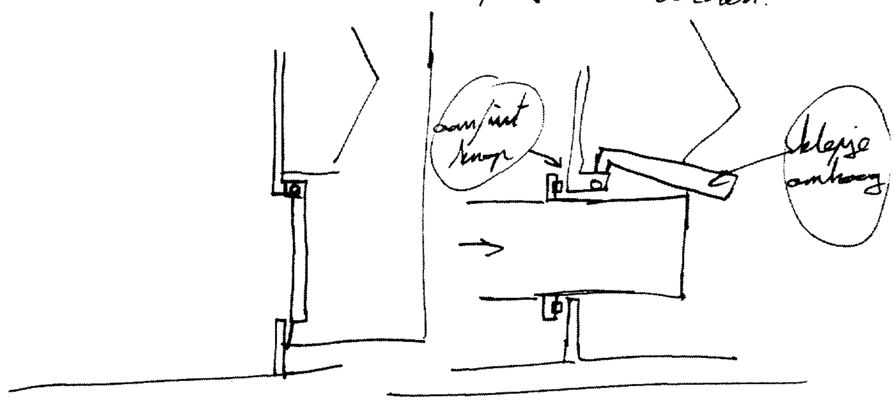
① treinwand a

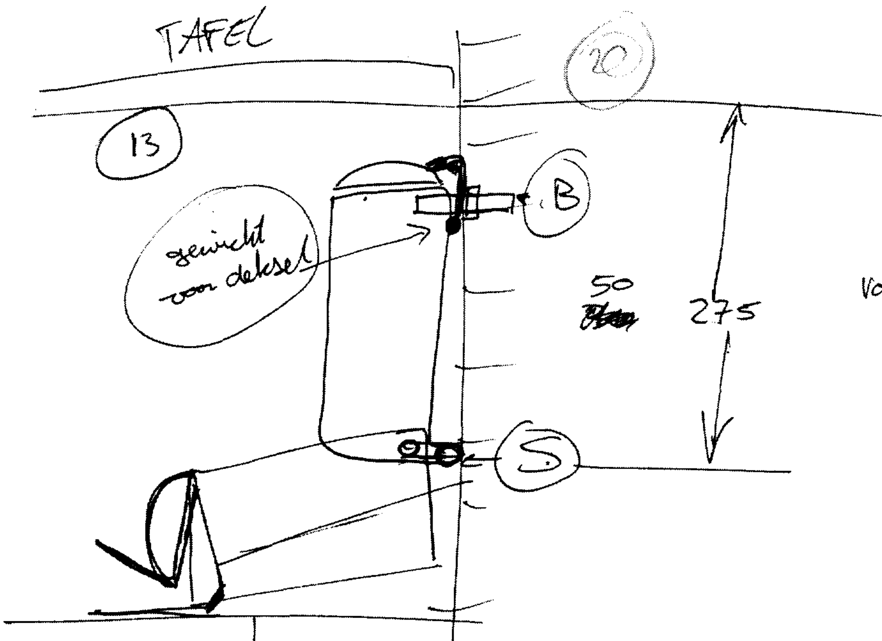
12



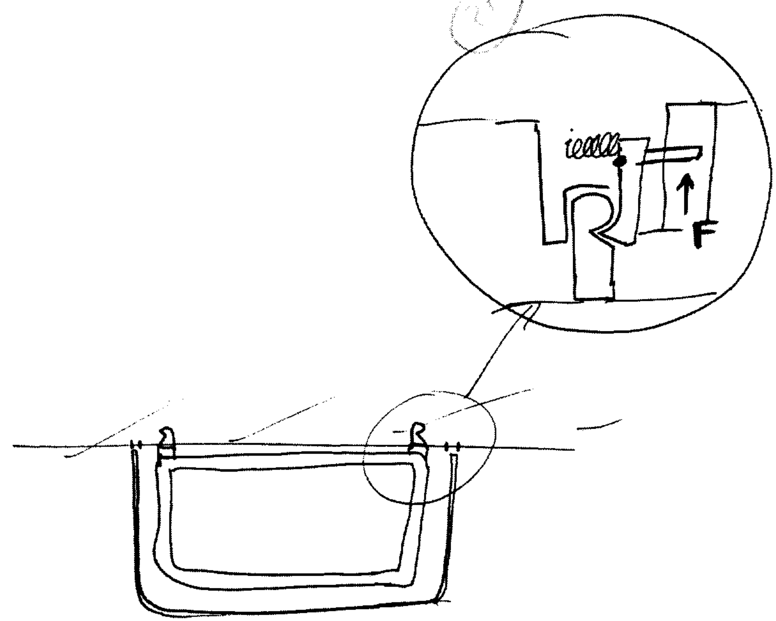
32

koppeling: * aan/uit voor stofzuiger
* niet lekken (lucht/vocht)
* niet vergrendelden
* klepje moet opengeduwd worden.





VOORDEEL: ~~BAK KAN VRIJ~~ MEER VORMVRIJHEID.



! : ontgrendeling alleen door leeghulpding !!

probleem: ontgrendeling:

Time	Strategy	Product elements	Constraints	Ideas
		(Read brief)		
		Lemmens'plastic refuse bin(w)		
		Current bin:steel/cast iron(w)		
		Emptying tool, that's unclear		
		(Reads brief)		
5		Q: Design for the SM90?		
		(A:Info card P.2)		
		Q: Study among passengers etc.?		
		(A:Info cards S.2.1/S.2.2/S.2.3)		
		(Views P.2)		
		(Reads S.2)		
8		Q: Info about emptying tool?		
		(A:Info card P.4.1)		
		(Reads S.2)		
		Present information:(w)		
		Inquiry passengers(w)		
		Q: What is the age of the subjects?		
		That influences the way it's answered		
		(A:Ages are unknown)		
10		Q: Is there a difference in bin between local and intercity train?		
		(A:Info card P.1.1)		
		I've never seen a lid		
		Then the SM90 is an intercity		
		(Reads brief)		
		No, SM90 is a local train		
12		Current sales promotion?(w)		
		Technical possibilities of Lemmens?(w)		
		Q: Lemmens: what do they manufacture?		
		Q: What is their specialism?		
		Q: What methods do they use?		
		(A:Info card S.3.1)		
		(Reads brief)		
		Q: Information about SM90?		
14		(Reads S.3.1)		
		Investment of fl. 80.000 is not much		
16		(A:Info card S.4.4)		
		(A:NS brochure S.4.4.F)		
		It looks nice		
		(Reads S.4.4)		
18		(Views P.4.1)		
		There is no lid on the bin		
		Yes		
		Q: There isn't always a lid?		
		(A:That's correct)		
		Q: Do I aim at the bin at the wall or in the seat?		
		(A:It's up to you)		
19		(Looks at concept bin: P2)		
		Only production possibilities are evaluated		

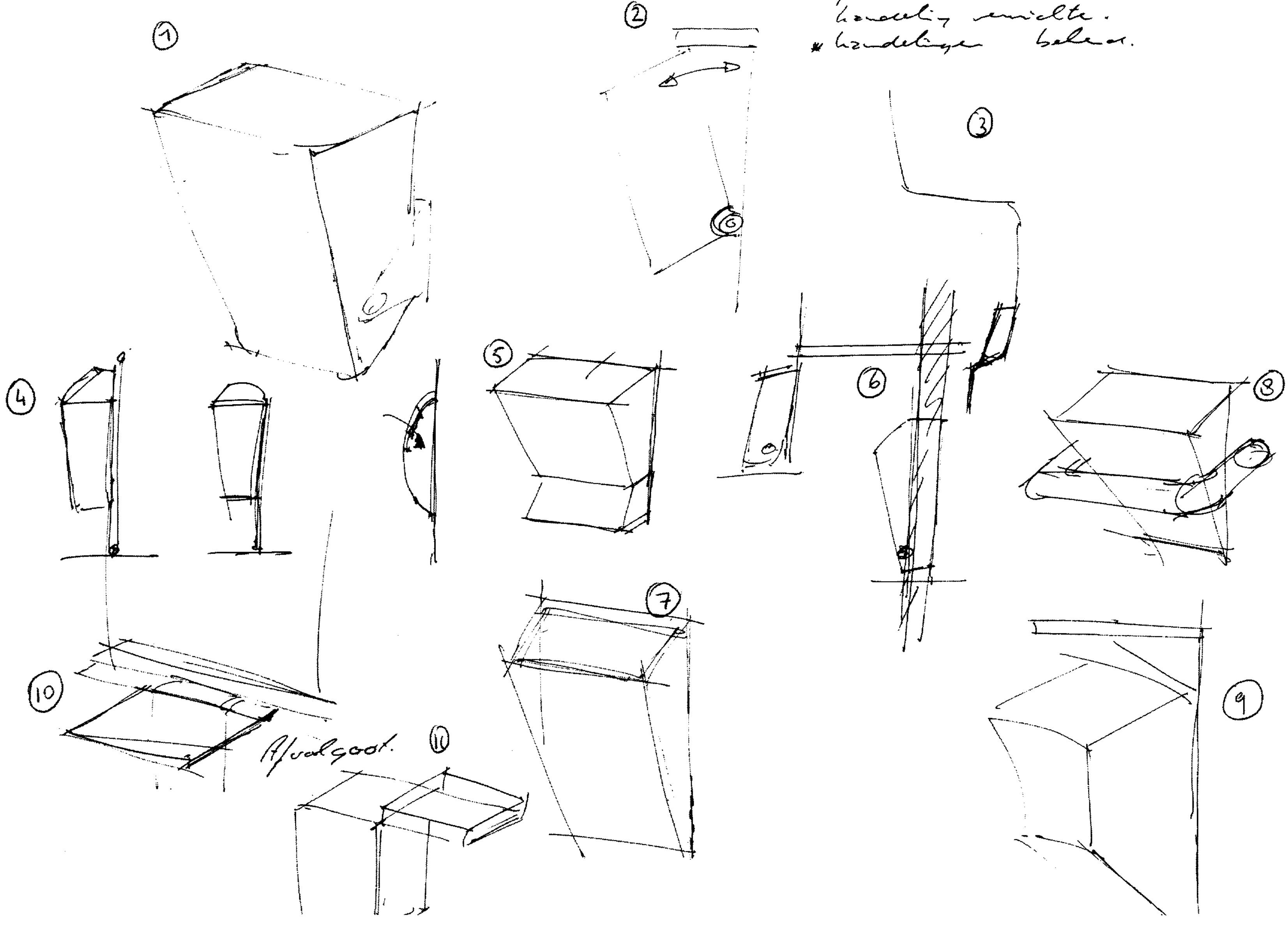
20		I can imagine P2 is not attractive		
		(Reads brief)		
		Q: Information on waste in bin?		
		(A:See info card S.2.3)		
21		Q: Are there defects in current system?		
		Q: With regard to vandalism, inflammability and fire		
23		(A:Info card V)		
		Q: I also want info on plastics?		
		Q: as to strength?		
		Q: as to fire-proof?		
		Q: as to production techniques?		
		(Looks at S.4.4.F)		
	I try to taste the atmosphere	Placing of the bin	In wall(w)	d
			In seats(w)	i
25		Lay-out train	2+3 formation	g
		Steel is better than platic		
		Think of the Pruiser bin		
27		Requirements of the bin	Plastic(w)	g
		Q: Are the bin sizes known?		
		(A:Info card P.1.3)		
		Requirements of the bin		
		(Reads S.2.1)	Dirty(w)	g
			It needs a lid(w)	d
			Automatically closing(w)	i
			It may not leak(w)	i
30			Attractive(w)	i
		(Reads S.2.2)	Quickly to empty(w)	d
			No chinks or holes(w)	d
		Q: Are the containers outside the train?		
		(A:Yes)		
		(Reads S.2.3)		
		(Reads V)		
34		Calculates the sizes of P.1.3)	The bin is 247x141x215=7,5 litre(w)	d
36		Q: What is the interspace between seats?		
		(A:Info card S.4.1)		
		That's the current situation		
		: Is there nothing about the SM90?		
		(A:Is not decided yet)		
		Q: Possibilities for connection to the wall?		
		(A:No more than information you have)	So I must start from connection of current bin	d
			That can always be adjusted	d
		Connection of P.2		
		Q: P.2 seems to have a round shape?		
		(A:No)		
		(Reads S.2.2)		
		Falling over: only 3%		
39		(Views P.1.1)		
		Current width		
		(Views P.1.3)	Not wider than 240 mm(w)	d
			Bin with or without lid	d
41		(Reads brief)		

		How far may a manufacturer go?			
		NS is slow in what they want			
		NS want new ideas or concepts			
45		(Views P.4.1)			
		(Reads brief)			
		Q: Did Curver offered the concept design?			
		(A:No)			
	I should start sketching	Q: Is there something known about the SM90 interior?			
		(Views S.4.4.F)			
		(A:Info card S.4.3)			
		It begins to look like a plane			
48		Q: Information about other refuse systems?			
		Q: In foreign trains?			
		(A:No, only other refuse bins)			
		Q: Bins of plastic?			
		(A:Info cards P.3)			
		Plastic material			
		That's of no use to me			
50		Q: Information about styling features?			
		(A:Not yet defined)			
		Q: Plastics: sorts and techniques?			
		(A:Info card M.2.12)			
		(Views S.4.4.F)			
54		Q: Brochure 'Train of the future'?			
		Maybe it contains nice illustrations			
55		(A:Brochure)			
	Let me formulate my thoughts				
	About how the current bin looks like	Current bin(1)			
		Flap-mechanism works well			
57		(Reads S.2.2)			
	I derive most information from inquiries	Production:can be arranged			
	The first idea must be good	Refuse bin	Must be with detachable lid	d	
			Supposing a detachable table	d	
		Q: Are there more ideas about the combination bin - table?			
		(A:No)			
		(Reads S.2.2)			
	The problem is to begin with something	Flipping bin, side-view(2)			
60					

K. Dijkman

II

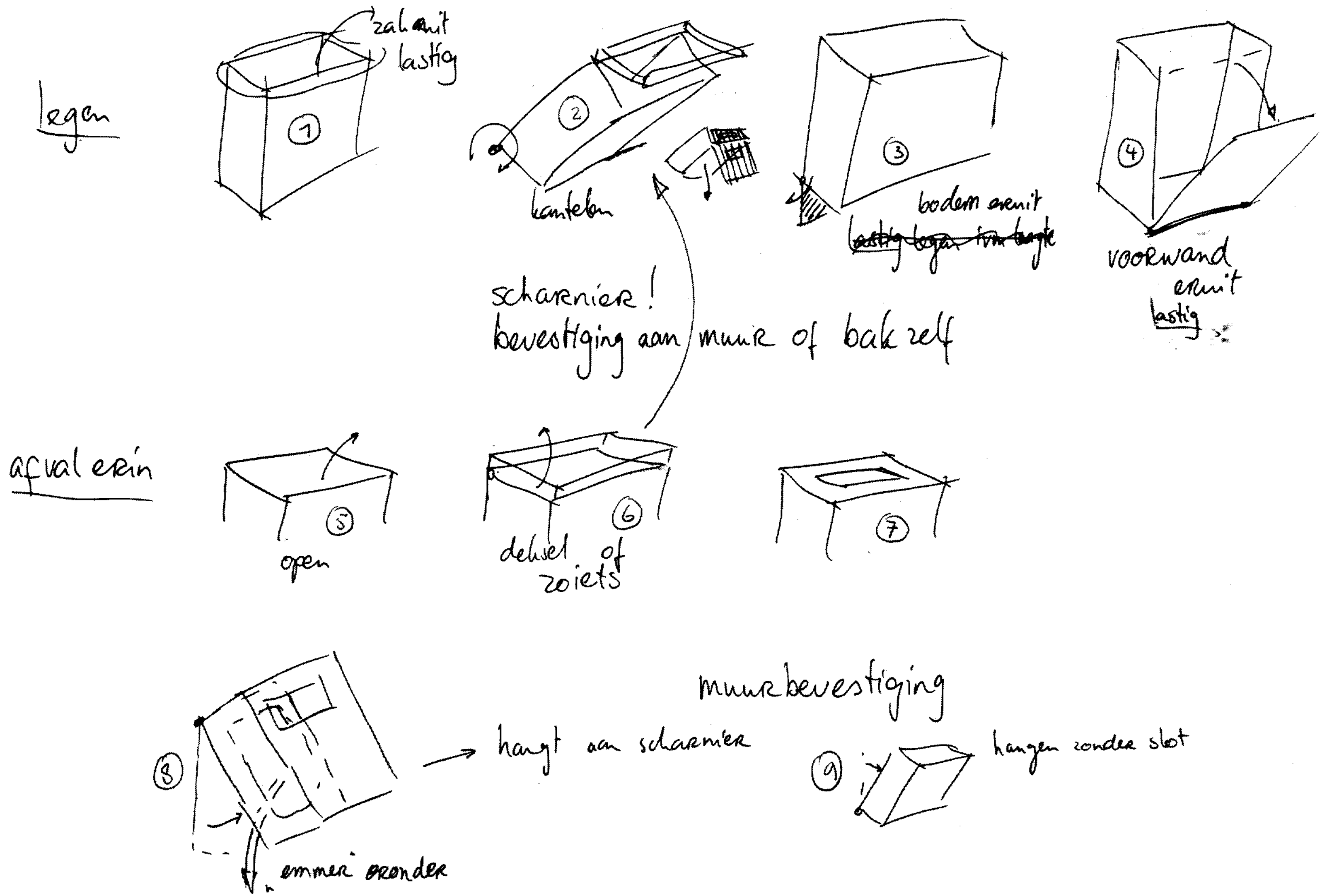
* Gebruiken zo min mogelijk handeling vereiste.
* handelingen beleven.



Time	Strategy	Product elements	Constraints		Ideas
		(Reads brief)			
2	I'll start with requirements		Waste has to be put in	d	
			Waste has easy to be taken out by cleaner	d	
			Waste may not easy be taken out by passengers	i	
		(Reads brief)	Refuse bin may not be too big	i	
			Refuse bin may not stand in the way	i	
			Waste easy to throw in	i	
		(Reads brief)			
5		(Reads brochure NS: S.4.4.F)			
		Q: What is distance between opposite seats?			
		A: (Lay-out compartment: S.4.1)			
8		(He measures existing bin)	Bin is about 30x20x15 cm	d	
			Placed at a height of 40 cm	d	
9	I'll start with the bin	Cleaning			
		Existing mechanism(sketches 1)			
		Cleaning mechanisms (1)			To turn over (2)
					Bottom out(3)
					Front wall out(4)
		Existing mechanism(1)	Sack difficult to take out	i	
11		Turn mechanism			
		Hinge			Connection to the wall
					Connection to bin itself
		Refuse bin	Waste easy to throw in	d	
			Easy to open	i	
			Easy to take out	d	
		Throwing waste in			
		Ways to open (5)			Kind of a lid (6)
13					Cut down the mouth (7)
15		Take bottom out	Difficult to empty if it is placed so low	d	
			Difficult to come underneath	d	
			Has to be solved with refuse sack	i	
		Turn-over (8)			Flap on backside (8)
					Bucket underneath
17		Connection to wall			To hang on hinge
		(Evaluation idea)	It must catch in order to	i	
			prevent emptying just anyhow		
19			If unlocked the bin may not fall forward	i	
21		Q:What kind of waste is in the bin?			
		A:(Inquiry kind of waste: S.2.3)			
		Content of the bin	Small things	g	
			Newspapers 40%	g	
			A big mouth is not necessary	i	
24		Q:What is wrong with the current system?			
		A:(Inquiry among passengers: S.2.1)			
26			Lid may not be dirty	d	
			Stench must be kept within the bin	d	
			Turnover mechanism may not fall open just anyhow	d	
28		Refuse bin	Proper lid	d	
			Not too much stoop	d	
			Possibly small refuse sacks	i	

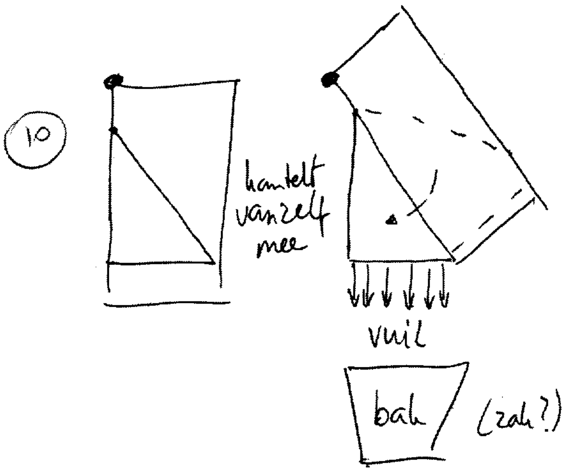
30			Quickly to empty in the dark Bin must catch when unlocked Possibility to take newspapers out No spots with emptying	d i d d	
		Emptying 'Unfolding' system(10) Collecting waste(11) Fastening sack			Turns over automatically Pulls bin forwards (10) Waste falls out (10) In bin or sack (10)
33		But that will become dirty Emptying (Evaluation idea) I have to know where the container is positioned			Flap at the bottom (12) Hinge at the backside (12) Pulling at the lid forwards (13)
36		One hand at the lid, and one hand at the bin (13) Throwing away of waste (Evaluation idea)	It stenches Therefore, a lid	d d	The mouth (14) The lid has to be opened (14)
39		(Evaluation idea) (Is reading survey passengers: S.2.1) Pushing and throwing away with one hand (Reads S.2.1 again) What more ideas?	By using the lid it will become dirty Difficult reach That's difficult	d g d	It can be opened with the other hand (15) Knob next to lid (16)
41		(Evaluation idea)	Is difficult with newspapers	d	A sliding-lid (17)
43		Control of the lid (He crosses it)			A pedal
46		Refuse bin (18) Emptying Using a waste sack Mechanism of the bin			Bin with a lid inside (19)(20) Hinge at the lid (21)
48		(Lid) (Evaluation idea)	With a round bin the hinge will not fit Front has to be flat (22)	d d	
50		Side-view of the bin (23) Form of the inner bin			
53		Side-view bin (26)			
55		Way of emptying (27) Inner valve and outside edge of bin Inner mechanism (28)	It would be nice when these parts fit together	i	
58		(Evaluation idea)	You will bump your legs Is not acceptable	d d	A rim in which the bin fits(29/30)
60					

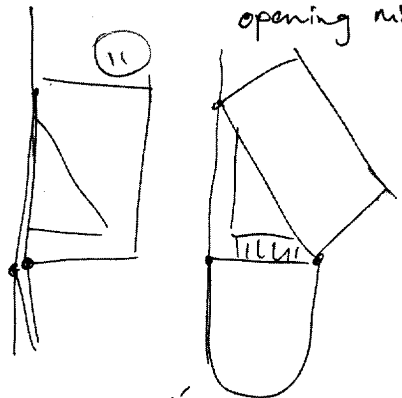
Schetsen

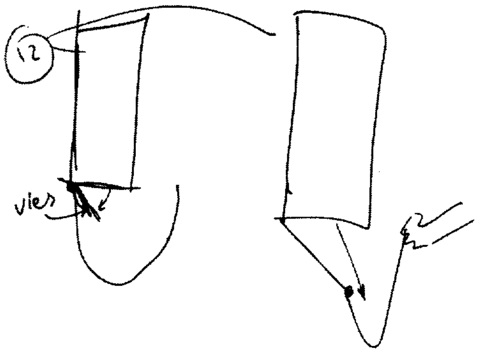

legen
zal eruit
lastig
kantelen
bodem eruit
voorwand
eruit
lastig
scharnier!
bevestiging aan muur of bak zelf
afval erin
open
deksel of
zoiets
muurbevestiging
hangt aan scharnier
emmer eronder
hangen zonder slot

XI

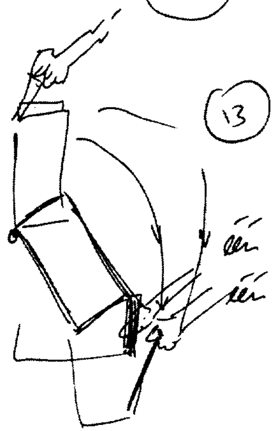
inhoud kleine dingen en kranten (40°6)
opening niet zo heel groot.

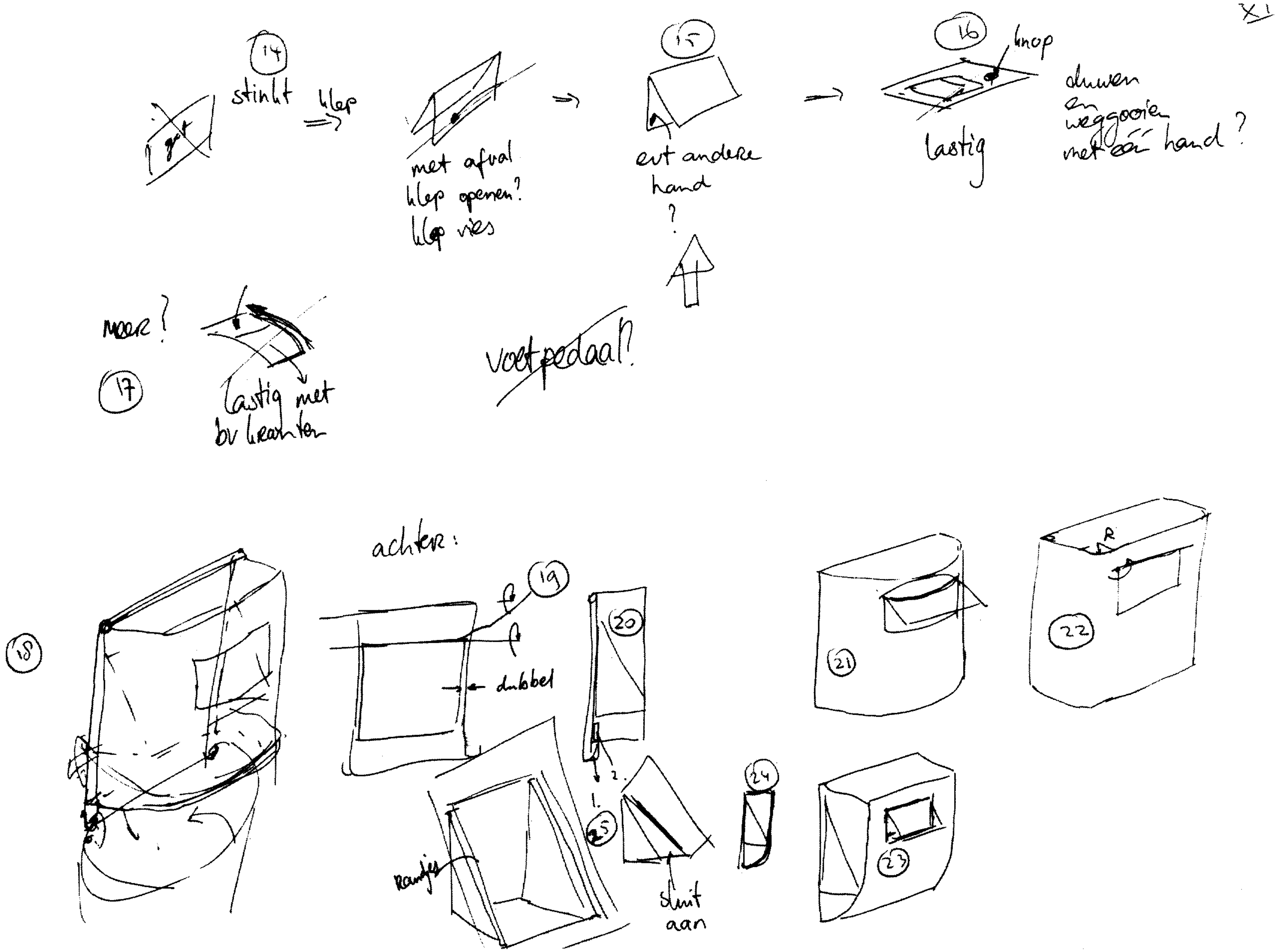


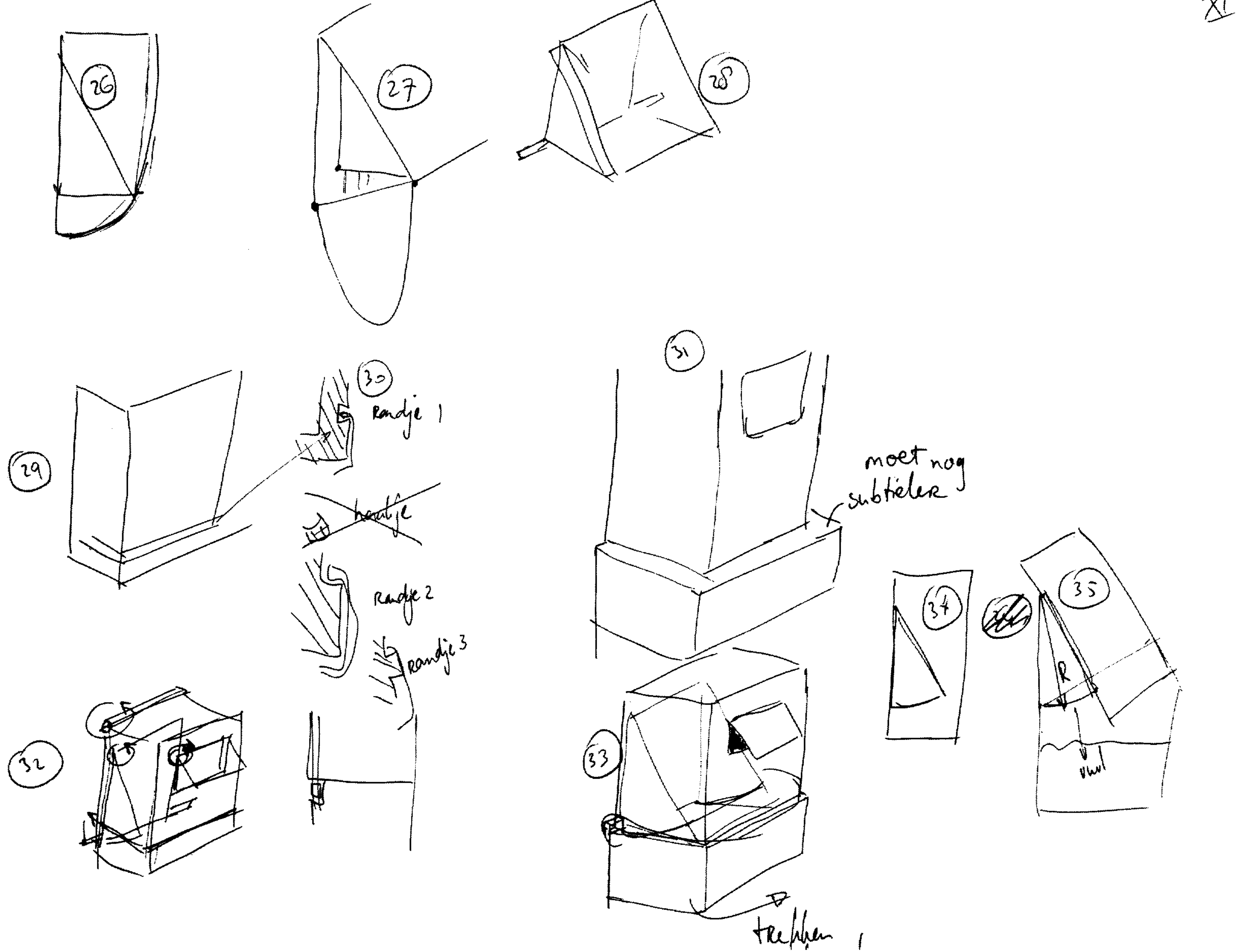




LEGEN




XI
14
stinkt
klep
met afval
klep openen?
klep vies
15
evt andere
hand
?
16
knop
lastig
duwen
en
weggooien
met één hand ?
meer?
17
lastig met
bv kranten
voetpedaal?
18
achter:
19
dubbel
20
randjes
25
sluit
aan
24
21
22
R
23

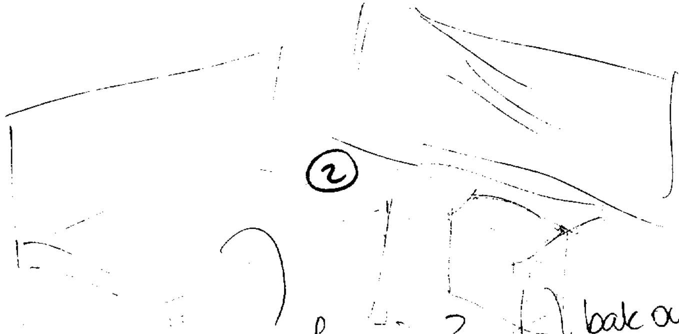

XI
26
27
28
29
30
randje 1
randje
randje 2
randje 3
31
moet nog subtieler
32
33
trekken
34
35
R
vul

Time	Strategy	Product elements	Constraints		Ideas
		(Reads brief)			
		A refuse bin is thus at stake(w)			
		With an emptying tool(w)	Aiming at passengers(w)	g	
			Made of plastic	g	
		Injection mould(w)			
		Vacuum form(w)			
		Roto mould(w)			
		Vacuum form and roto mould	That's only for small series(w)	i	
		I have to know the series			
3		Q:How large is the series?			
		(A:5600 a year for 10 years)(w)			
		Not really a large series	They'll choose roto mould	d	
			or vacuum form	d	
			They can do it themselves	d	
			instead of contracting it to another	d	
		Must be possible in both cases			
		They want to reduce suppliers	So they choose injection mould	d	
		2+3 seats in a row			
		Q:Are seats located opposite or in the same direction?			
		(A:Opposite)			
		Q:Always or sometimes?			
		(A:Sometimes)			
5		Q:I cannot always place a tray in the back?			
		(A:No)			
		It's not really a big series	So, difficult to diversify much	d	Best solution is: a bin aside for all seats
	The task is that I give a solution				
	Solution(w)				
	Realization(w), represent the idea				
	Technical drawing(w)				
	Cost estimation(w)				
	I need 2,5 hours for that				
	Half an hour is for the drawing				
	Half an hour for the cost estimation				
	I have 1,5 hours for idea + elaboration				
7		Because 3 seats are located in a row	A bin should be placed aside a seat	d	
9		Let's have a look at the train			
		(looks at brochure S.4.4.F)			
		(reads info on SM90)			
11		(reads brief)			
		Q:Can I have info about: kind of waste, and opinions of passengers and cleaners			
	I wonder if they think the same as I do				
	If they are also annoyed	(A:Info cards S.2.1, S.2.2, S.2.3)			
		Q:Is it studied after current bin?			
		(A:Yes)			
		Q:Is too big waste taken into account,			

		that people take home?			
		(A:This is what they find, and what users think)			
13		Many newspapers and cups			
		(reads information)			
		Q: What kind of emptying tool have cleaners?			
15		(A:info card P.4.1)			
		You put it in and cant it			
		Lid is not always taken into account			
		That's not clever			
		The lid must opened first			
		before emptying the bin			
		The complaints are:	Refuse bin is too wide	g	
		Some remarks are irrelevant	Train light is already turned off	g	
			Stale work	g	
		Q:Are bags in bins considered?			
		Is that possibility investigated?			
		(A:We don't know, no investigation)	Not justified for ecological reasons	d	
17		Content: many newspapers and cups(w)			
		Most of it are newspapers	Biggest complaint: too small	g	
			Newspaper doesn't fir either	d	
			Dirty lid	g	
			Just dirty	g	
		Q:Emptying tool in bin, not enclosing?			
		(A:In the bin)			
		Liquid will run on the floor			
19		You want a refuse system:	Bigger bins(w)	d	
			Which are less dirty(w)	d	
			Which do not spill while cleaned(w)	d	
		Current bin	It's not within easy reach	d	
			Both to passenger and cleaner	d	
			Because they must pass the seats	d	
			Bin in gangway is not clean either	i	
21		Emptying tool is essentially practical	It need not changed much	d	
	I start drawing a bin				
23		Location of the bin(1)	It must located near the seats	i	
			With a 2+3 formation not too far away(w)	i	
		Q:Are there also tables?			
		(A:Interior is still not designed)			
		Q:Table in current along the window?			
		(A:Yes)			
		(Location of the bin)			Underneath the table is the best
		Disadvantage of current bin	Third person cannot reach it	d	
		(Location bin)			Underneath the seat
		Disadvantage of bin underneath the seat	Difficult to clean	i	
			You can also leave your luggage there	i	
		Location of the bin(2)	So, beneath the window anyway(w)	d	
25		A three-sitter			
		Six opposite to each other	That's 2 times the amount of waste	d	
			Or at least one and a half times	d	
			So bigger bins are obliged	d	
		Number of bins			I consider 1 bin in normal situations, and 2 or even 3 when it's really busy(3)

					Or to use a number of small bins(w)
		Newspapers caused a problem			Beneath I can place a separate
					newspaper- plank (w)(3)
		Then there's more room in the bins			
27		Separate collecting of waste	That's always favourable to environment(w)	i	
		(Size of the bin)	Without newspapers bin don't need bigger	d	
			Maybe the current bin is big enough	d	
			The other waste doesn't contain	d	
			big things	d	
		Refuse system			Modular system(w)
					Dependent on number of passengers
					Different number of bins
		With more bins(w)	Larger series(w)	d	
			Costs are lower then(w)	d	
			provide that they are alike	d	
29		(Location bin)	Bin in gangway is unacceptable	i	
			Because you must pass dirty bins	i	
			It's at the expense of seating or gangway	d	
			There is already a seating shortage	i	
			Only underneath the seats is possible	i	
			But that's a place for luggage	d	
			Against the wall is the only possibility	d	
			Underneath the window	d	
30					
		In connection with cleaning:(w)			Removable bins(w)
					You can exchange
		Disadvantage of removable bin:	Theft-prone(w)	i	It must get a lock(w)
31		Q:What are the sizes of the current bin?			
		(A: info card P.1.3)			
		Current bin is 21x14x25 cm(4)(w)			
	What can I derive from it?				
35		I suppose a newspaper is A4: 30 cm	Bigger is ok in case of more bins in a row	i	
		If I should have 1 bin(5)			which is of equal size, 21 x 14 x 25
					Newspaper-shelf beneath, or a basket(6)
					A basket for newspapers
37		The size of a basket	30 x 15 is allowed	d	
			Waste gets through it(w)	i	
		(Material bin)	Close plastic(w)	d	Basket also made of plastic,
					a kind of crate
		With 2 bins(7)			1 newspaper-shelf(7)
39		With 3 bins(8)			With 3 bins 2 baskets are possible(8)
					Let's make the cube somewhat bigger, 35
		Size:70 divided by 3 (8)			I want some room in between,
					in order to clear out
		Size	So it must remain 21	d	
			Thus 63 is left	d	
			Then I have an interspace of 3,5	d	
		There I can locate the support(w)			
41		Depth of the bins)	I would say 15 deep	i	
			II must clear out the bins	d	
			Shelf may not be in the way	d	Hinges here
		(Bin-seat location)	This is with 2 seats in a row	i	
			This is with 2 seats facing 2 other seats	i	

			This is with 2 seats in a row Two or three bins	i i	
43		Q:Is room for legs 70 cm? (A:Measures not exactly known) (A:Sizes current train: S.4.1)	(A:New train is 30 cm wider	g	
44			Is that only 46 cm? 46 is maximum with 3 in a row	g i	
46		Not nice to the last seat (A:Some cm wider between the seats) Q:But not 20 cm? (Sure no) Underneath the chair is not nice			I can make a deeper bin Two bins in a row is possible
48		That's a doubling compared to current situation One big bin is not practical Because in that case you need different emptying tools Sizes			Two in a row is a maximum
50			Here it is 46, and here 37 That can remain 35: less waste in the bins	d d d	
		In spite of dirty lid Without table a lid is needed	So, there the lid must remain Some bins with a lid and some without Dependent on the formation of seats	i d d	It opens automatically when looking at it
52 60					

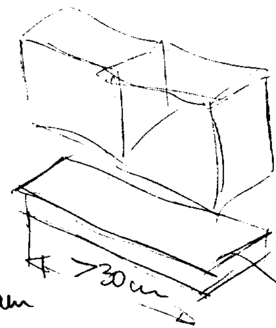


(2)

bak onder raam

2 of 3 zits?

meerdere kleine bakjes XII
in plaats van 1 grote!



(3)

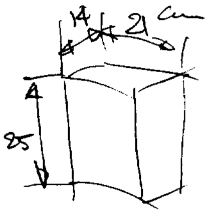
apart krauterplankje?
⇓ milieu!

MODULAIR SYSTEEM.

meerdere bakjes (dezelfde)
= grotere serie = lagere prijs.

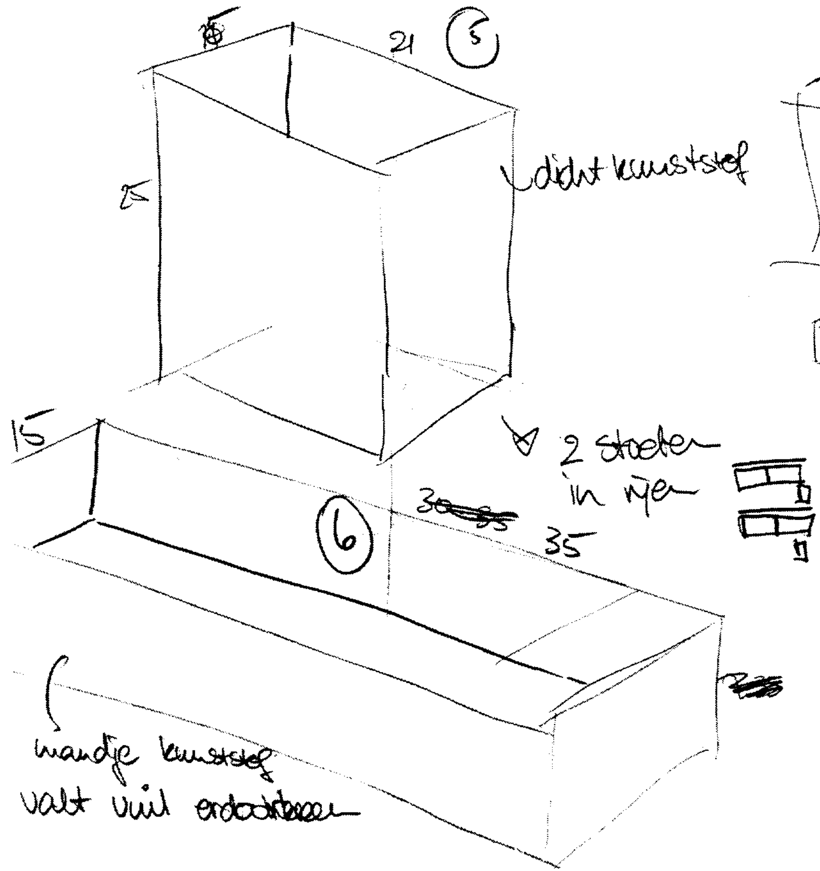
- afneembare bakjes = schoonmaker
- diefstal ⇒ slot

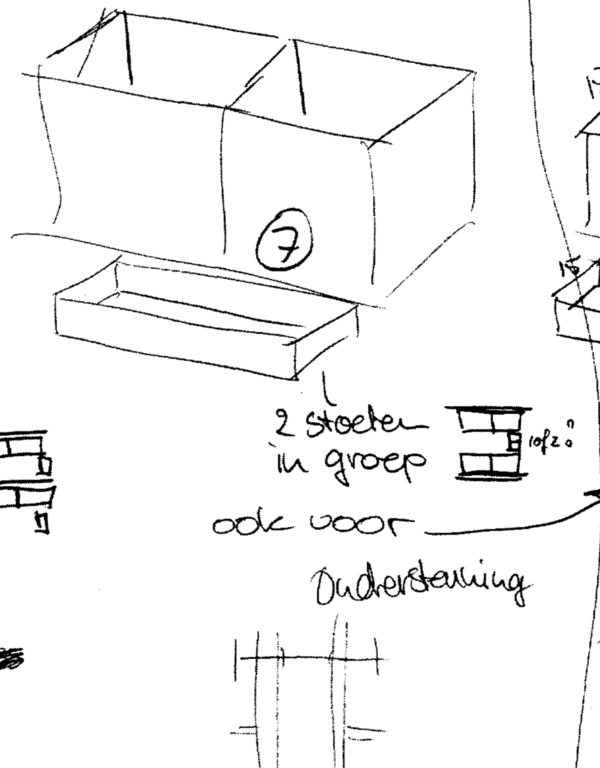
bestaande bakje ≈
staal
⇓
kunststof

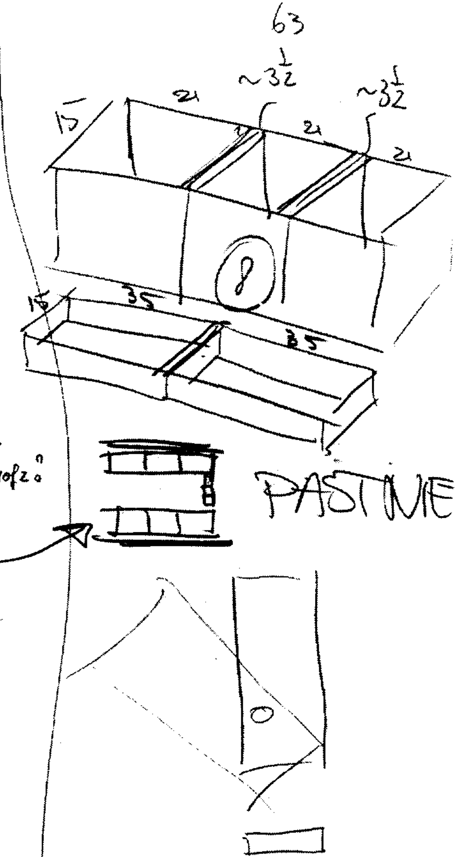


(4)

$70 : 3 = 23\frac{1}{3}$







met deksel / zonder deksel

|| achter elkaar zittend (passagers)

|| tegenover elkaar zittend.

100 bakje + 200 = 300 P

100 mandjes + 100 = 200

$1\frac{1}{2}$ × zoveel bakjes als mandjes

≈ 5600 bakjes / jaar

= 3700 mandjes

Authors index