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Teamwork and Design Methodology—Observations About Teamwork in Design Education

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Abstract. *This paper focuses on the topic how students can learn to cooperate in design teams, to be prepared for industrial practice. Advantages and disadvantages of teamwork in design are observed in a project. In this project students designed and manufactured a device in teams. Most of the disadvantages which are discussed, occur because of problems of communication between the team members. An approach for the education in systematic design and the experiences in using this approach are presented. The paper concludes with suggestions for design education and for research.*

Zusammenfassung. *Der vorliegende Beitrag beschäftigt sich mit der Frage, wie man Studenten schon in der Ausbildung die Fähigkeiten zur Zusammenarbeit in Konstruktions-Teams beibringen kann, um sie auf die Praxis vorzubereiten. Anhand eines Projekts, in dem Studenten im Team ein Gerät konstruierten und herstellten, werden Vor- und Nachteile der Teamarbeit beim Konstruieren beobachtet. Die Nachteile, die diskutiert werden, enstehen vor allem durch Probleme der Kommunikation zwischen den Teammitgliedern. Ein Vorschlag für die Ausbildung von Studenten beim methodischen Konstruieren im Team wird vorgestellt und die Erfahrungen bei der Umsetzung werden dargestellt. Anregungen für die Konstruktionsausbildung, die aus dem dargestellten Projekt enstanden, sowie Ansätze für die Forschung schließen den Beitrag ab.*

Keywords. Design education; Mechanical engineering; Methodical design; Teamwork

1. Introduction

Today, one of the most important factors for successful product design in mechanical engineering is successful interpersonal cooperation [1, 2]. When design methodology was developed, teamwork did not have today's significance for the work of engineers. Research in design methodology concentrated more on the design process of individuals. Recently the introduction of Simultaneous Engineering and Concurrent Engineering has added to the importance of teamwork in the practice of product design. In the framework of education, however, the significance of design teamwork has not yet been fully recognised [3]. For this reason, the Faculty of Design in Mechanical Engineering at the Technical University of Munich has introduced a project in design education which is presented in this article. The project had the following objective: Students should practise design work on a concrete device while taking into account the practical aspects of production. This was achieved by the requirement that students had to manufacture their device themselves in a workshop. The element of teamwork was promoted by the fact that groups of three students worked together to produce one device.

The following questions relating to the integration of teamwork in the concept of design were examined in the course of the project:

- Which difficulties can occur during teamwork in design?
- Under what conditions does a design team utilise the advantage of the methodical approach?
- Does the methodical approach have advantages for teamwork or is design methodology in its present form more suitable for the design processes of individuals?

2. Overview of the project

In the framework of a pilot-project, four groups of three students each, were observed while designing and manufacturing mechanical devices [4]. Two weeks were allowed for designing and three weeks for

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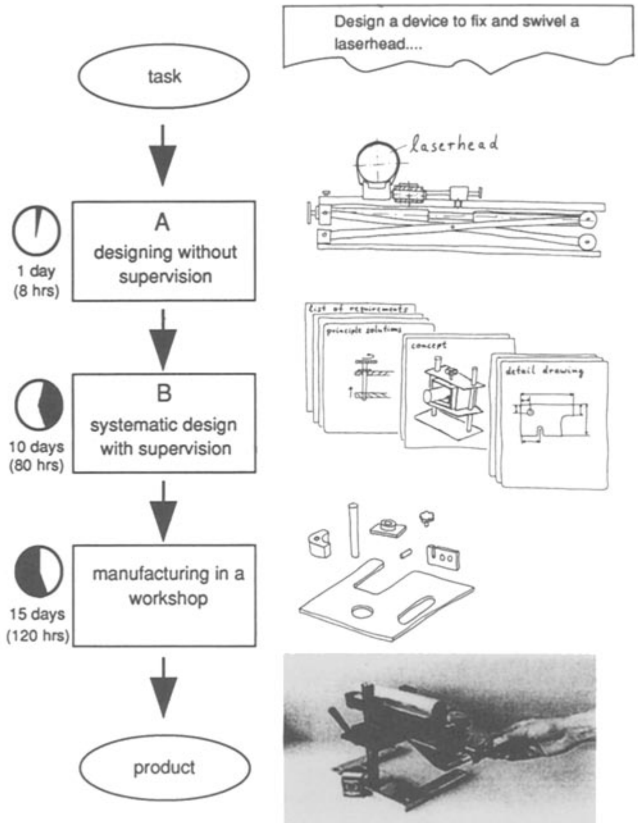

Fig. 1. Overview of the course of the project.

manufacturing. The teams completed the whole process of developing a new device—from the clarification of the task to the final product.

The course of the project can be illustrated as shown in Fig. 1. The task was set in writing. As a result of the design process the participants were required to produce layout drawings, detailed technical drawings and a list of parts.

During designing the students were supervised by two teaching assistants on the basis of the steps of design methodology [5–7]. While manufacturing in the workshop, the students were supported by the master craftsman and apprentices.

The first day of work was an exception to this pattern. During this day the students, who had not been exposed to design methods yet, worked on their problem without supervision to create a first layout. The supervisors gave no assistance in this first period and only answered questions about the task. This work situation corresponds to the setup Dylla [8] used for design experiments.

The first day, as well as the whole process, was recorded on video so that the team approach could later be discussed with group members and the differences to the approach taken under methodological supervision could be analysed. For the video analysis similar techniques as explained in References 9 and 10 were used.

From the second day onwards until the end of the design process, the students were supervised. The supervisors defined intermediate aims (*Zwischenziele*), provided methodological aids (e.g., methods for evaluation of solution principles, see Ref. 6, p. 204), chaired the team discussions and the design process.

Sufficient time was provided for the introduction to design methods. The important aspect of supervision was that the teaching assistants did not themselves suggest solutions or evaluate those presented by the students. Their purpose was solely to accompany the systematic design process without taking an active part in designing.

After each design step the students were interviewed on the following questions:

- Was supervised teamwork more successful than during the first day and why?
- Which interpersonal problems and which technical difficulties occurred during work?

Important clips from the video documentation, according to the opinion of both the supervisors and the students, were shown and together analysed during discussion.

3. Design task

For the setting of the task the following requirements were taken into consideration by the teaching assistants:

- The task should have a suitable degree of complexity so that a methodological approach (with a division into sub-problems, creation of solution variations, etc.) is applicable but does not take too much effort.
- The development and detailed design of the solutions should be possible without specific technical knowledge. The participants in the project, engineering students in their 6th or 8th semester, should be able to complete the design without additional special knowledge.
- The time from the clarification of the task to the finished detailed design should not exceed two weeks.
- The manufacturing of the device designed should not exceed the three weeks provided.

On the basis of these requirements a design task of medium complexity was prepared for the project by the assistants. The device is anticipated to consist of 40 to 50 parts, depending on the developed design. The task was presented to the students in the form of a written specification and can be summarised as follows:

A device to fix and swivel a laserhead is to be designed. The laserhead is used in optical experiments. Information about dimensions, weight of the laserhead and directions and angles of movement are provided. Movement and adjustment of the laser in the required directions are to be made by hand. The device is a "one-off-prototype" which has to be manufactured with low costs in a workshop. Aim of the task is a layout drawing and detailed design drawings for manufacturing and a parts list.

The complete task is described in a report by Giapoulis and Günther [4].

4. Team Members

The participants in the project were mechanical engineering students at the Technical University of Munich (3rd year of education). They had no education in design methodology.

Concerning the combination of the team members it was important to assemble groups of previously unacquainted individuals, so that the students did not already have certain role-relations (e.g., through friendship, etc) at the beginning of the project. Thus, all members of the team faced the same situation to integrate into a team and to cooperate with others.

Relating to the setup of cooperation within the group it is relevant that the task (during conceptual and embodiment design) was not divided into subtasks that could be delegated to individuals and thus completed independently. This insured that all students experienced all the problems the design task presented. Each team member was equally responsible for the whole design. A division of work was only allowed during the detailed design and manufacturing.

It was an objective to create groups that were homogenous in their members' degree of experience and design knowledge, in order to avoid the development of a hierarchical structure within the teams.

5. Observations and Results of the First Day

During the first day, the student teams worked out a first layout of the device. The interviews with the participants revealed that the result of the first day was dissatisfying, not only for the supervisors but also for the students as realised in the interview. One result of the first days' process is illustrated in Fig. 1 (top right). The design solution is too heavy, difficult to manufacture and needs a large space.

According to their statements in the interview, the students had:

- Difficulties with the creation of an overall concept (*Gesamtkonzept*), although there were no difficulties with the creation of solution principles for sub-functions.
- Difficulties with comprehension and imagination of solution principles during the discussion in the team, because there were no suitable illustrations.
- Difficulties with agreement in the team on the evaluation and selection of solutions.
- Difficulties with the simultaneity of understanding other members' proposals and the development of one's own solutions.

5.1. Advantages and Disadvantages of Teamwork

After the analysis of the approach taken by the teams and after the discussion of the first day material (videos, interviews, drawings, notes) the following comparison can be made between teamwork and individual work. This comparison is based on the personal statements of the students which are made against the background of their studies' experience. They are, therefore, only qualitative and subjective statements. However, they are fully supported by their supervisors who can draw on an expansive teaching experience:

- Teamwork leads to a better clarification of the task.
- Teamwork leads to the creation of a greater variety of solution priciples.
- Teamwork leads to a more intensive analysis of the solutions presented.

However, phenomena occurred which countered these advantages and sometimes even rendered cooperation in the team impossible.

Discussions in the team were often influenced by the dominance of individual team members ('who talks loudest has the most important thing to say'). Dominant team members tried to get the attention of the others to present their solutions. Results of that dominant behaviour are:

1. The team moves on directly from the clarification of the task to the searching of solution principles, as soon as a dominant team member presents a suggestion. By that, the clarification of the task is interrupted and the team swiftly proceeds to develop the suggested solution until it proves unsuitable or until unconsidered requirements

occur. Good suggestions for solutions are lost or fail to be documented because the presenting team member is not sufficiently dominant.

2. 'Slower' team members do not have enough time to introduce their solutions in the discussion. Each team member has to develop solutions of his own, as well as to analyse and improve the solutions presented by others. Consequently, the team members who need more time for the elaboration of their own ideas or who set very high standards before presenting them, are forced to deal predominantly with the ideas of others and are hindered in generating their own solutions.
3. Team members' fixation on their own ideas leads to subjective evaluation and a preference for their own solutions. The subjective over-evaluation results in indifference towards other members' suggestions and in their rejection without sufficient analysis. The tendency to prefer one's own or well-known solutions can also lead to the loss of acceptance in the team. Further suggestions from the same person get rejected by the team and subjective and personal criticism deteriorate the work climate.
4. Problems of understanding among the team members can lead to long and arduous verbal explanations. If this occurs repeatedly and is time consuming, it can result in a loss of motivation and reduced cooperativeness. Problems of understanding are most frequent in the context of unclear or missing sketches and illustrations.
5. Often, solutions found for a sub-problem lead to the team's attempt to complete the embodiment design straightaway. This usually overtaxes the team. The intersections of parts, spatial arrangement of the device, degrees of freedom, etc., are not sufficiently considered. In attempting to develop an overall concept directly on the drawing board, alternative solutions are not considered anymore. Occurring mistakes are improved by small detail corrections of the existing design. Sometimes even the requirements for the device are changed in order to keep the existing concept. The team members have no time or motivation left for the creation and evaluation of alternative concepts.

6. Teamwork Under Supervision

In the following section, the methodological steps that the students completed under supervision and the observations of the supervisors are explained.

6.1. Approach of Teamwork Under Supervision

1. Generation of a requirements list
The students listed the requirements of the task in teamwork. After that a list of questions was created, with which the students interviewed the teaching assistants. This revealed issues and questions that had not explicitly been included in the text setting the task (e.g., the precision of adjustment and frequency of adjustment).

2. Structuring the task in sub-problems
The overall function of the device was divided in sub-functions: Adjustment in the horizontal and vertical plain, height adjustment, locking of the adjustment mechanism, fastening of the laserheads to the device. This prepared and structured the search for solution principles.

3. Search for solution principles on an abstract level
Abstracts of solution principles were collected and documented in sketches. In this step, students worked on their own as well as in the team. Each team member developed solutions for all sub-problems.

4. First evaluation and selection
Using a method of selection (selection chart from Ref. 11 (p. 113) unsuitable solution principles were rejected. The selection was conducted in the team.

5. Concretisation of the solution principles and variation of working structures
The solution principles were further concretised in sketches. The variation of the working structure was then carried out in the team. Variation of working structure (see Ref. 4, p. 378) is defined as the systematic alteration of characteristics of the solution (see Fig. 2). The team members presented their solutions which were already documented. Then each student had to pick up the others' ideas and suggest improvements or develop further variations of the working structure. The generated solutions were ranked and classified by the team.

6. Selection of the most suitable solutions
The participants decided on evaluation criteria and agreed on a common evaluation scale. Evaluation and selection of solutions was also conducted in the team.

7. Combining the selected solution principles to concepts
The selected solutions were classifed in a morphological matrix (see Fig. 3). Within this matrix, the selected solution principles were combined to form

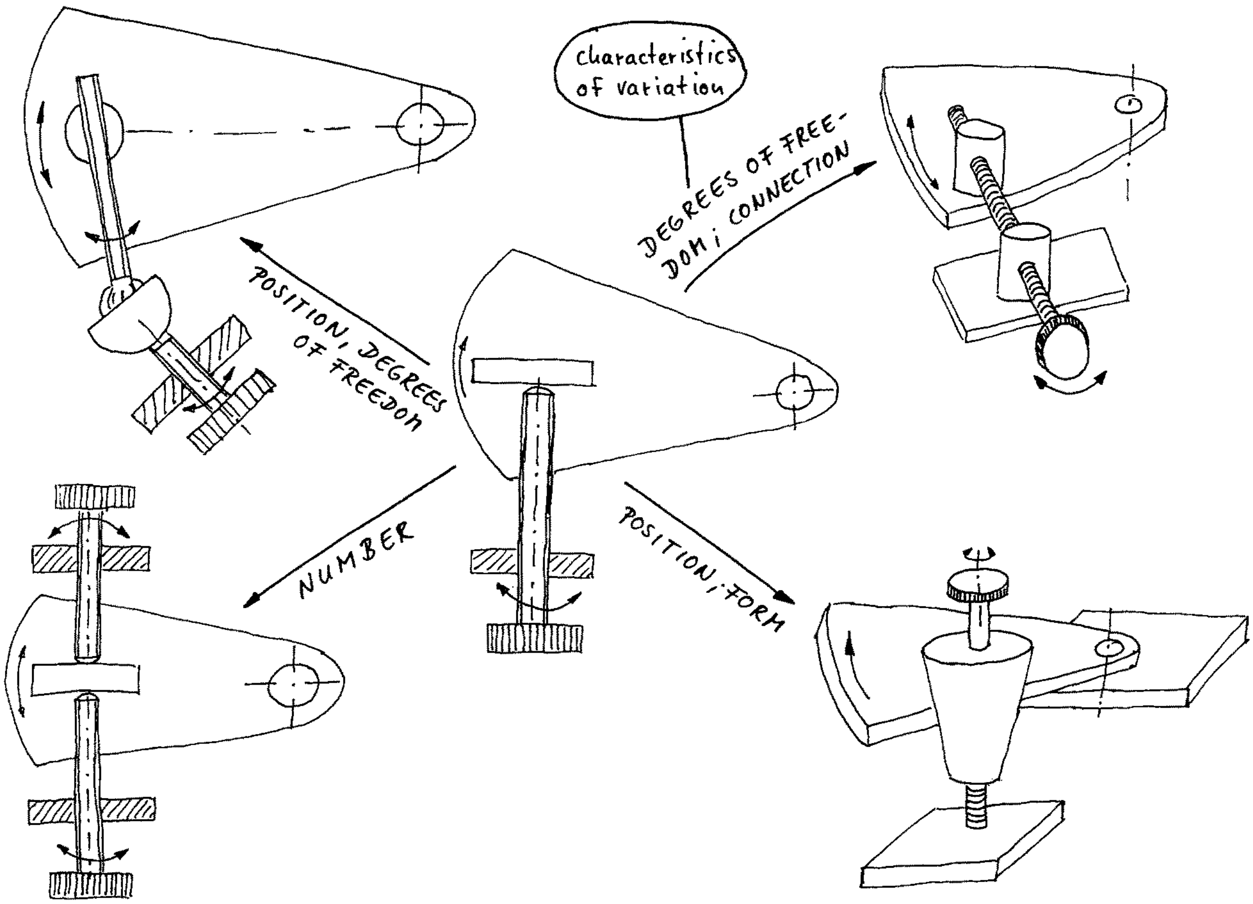

Fig. 2. Examples of the variation of the working structure.

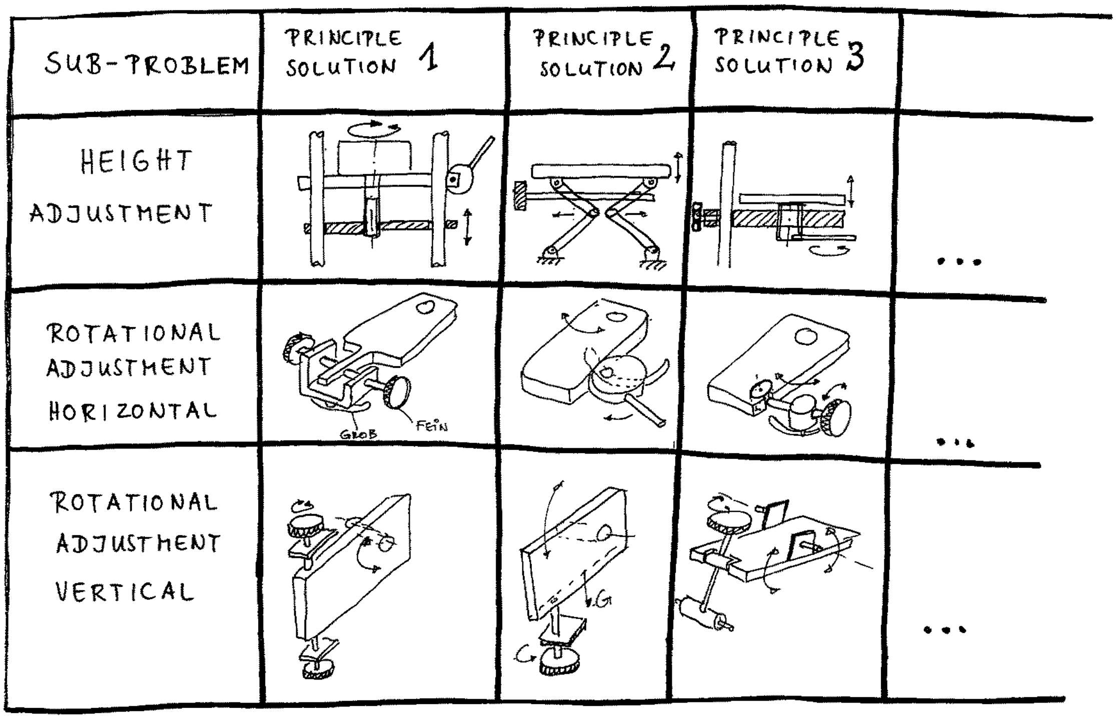

Fig. 3. Morphological matrix.

concepts. The overall concepts were illustrated as 3-dimensional sketches. Figure 4 illustrates a concept developed by the students.

8. Embodiment design of selected concepts
A selected concept was further elaborated in several steps to create a layout drawing to scale. Additional design aspects like lack of space, assembling, manufacturing and specific qualities of work materials were considered here.

9. Detailed design
In the step of detailed design the production documents (drawings and parts list) were created. The students were allowed to divide the work and distribute it among themselves. The documents were checked and improved in a two-step procedure.

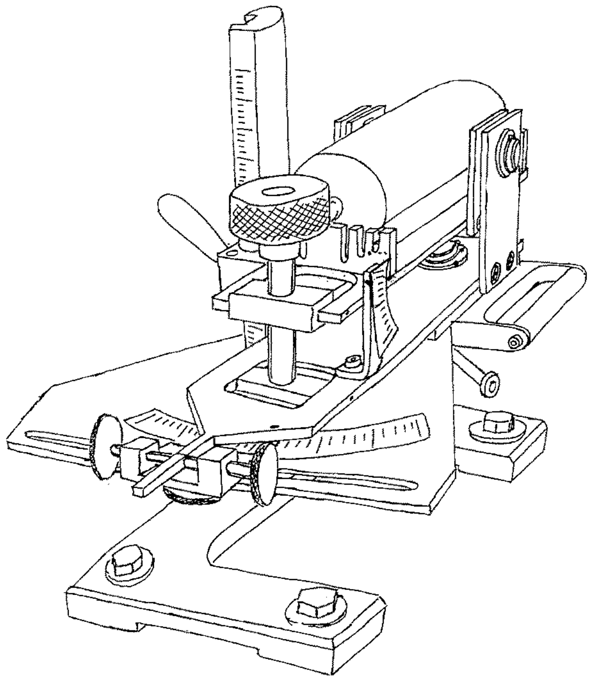

Fig. 4. Concept of a student team.

6.2. Observations During Teamwork Under Supervision

Analysing the students' interviews and the observations made, the following results and differences to the first working day become apparent. The use of design methodology supported the teamwork in the following aspects:

1. The full completion of the list of requirements before beginning the search for principal solutions provided a general group consensus on the objectives and prevented the team from forgetting essential requirements.
2. The division in sub-problems facilitated the search for solutions and the classification of sub-solutions. This, in turn, simplified later evaluation and made the creation of an overall concept by combination of sub-solutions much easier.
3. The assignment of sub-solutions to sub-problems and the documentation of all solutions through sketches prevented good ideas from being lost in the team process.
4. The completion of the step 'search for solution principles' before moving on to the variation of the working structure helped the 'slower' team members. They had sufficient time to elaborate their ideas before dealing with the evaluation and improvement of others' ideas.
5. The time lag between the search for and the evaluation of solutions, led to the advantage that no principal solutions were lost due to premature rejection. On the first day solutions had often been immediately criticised upon their presentation and had consequently not been documented any further.
6. The documentation of the sub-solutions and the classification to the sub-problems had a positive influence on the creation of the overall concept: for the team, creation of the concept now meant the combination of sub-solutions that had already been developed and classified. This enabled the students to create alternative concepts by the use of sketches, explain them to the other team members and improve them in the group. This process proved extremely time-saving and motivating for the participants. Several alternative concepts were developed and the most convenient was selected.
7. The variation of the working structure led to the creation of a wide variety of alternative solutions. This revealed another advantage of teamwork: the fact that every team member assessed and developed everybody's solutions avoided the individual fixation on one's own ideas. After some steps of variation it was impossible to tell who had created which solution. This facilitated objective technical evaluation and cooperation within the team.
8. The evaluation on the basis of commonly agreed criteria leads not only to the selection of good solutions for the sub-problems, it also prevented

emotional argumentation, as 'I think my solution is much more attractive'. By choosing a systematic approach and using commonly accepted criteria of evaluation, misjudgement and conflicts between team members were avoided.

9. The clear and precise documentation of the solution principles in sketches and the classification of the sketches according to sub-problems was an important factor in the discussion and communication among the team members. Time consuming oral explanations were avoided and solutions were communicated quickly and comprehensively.

As a general observation, it is clear that the structure of the methodical approach under supervision helped the students to overcome the problems mentioned in Section 5.1 above (dominant personalities, loss of solutions, fixation on own solutions, rejection of other peoples' solutions, difficulties of concept creation). Other researchers observed similar problems in case studies, too [12, 13]. During detailed design and manufacturing, no further conceptional alterations were necessary and the products manufactured met the functional requirements of the task. Figure 5 shows a device manufactured by the students.

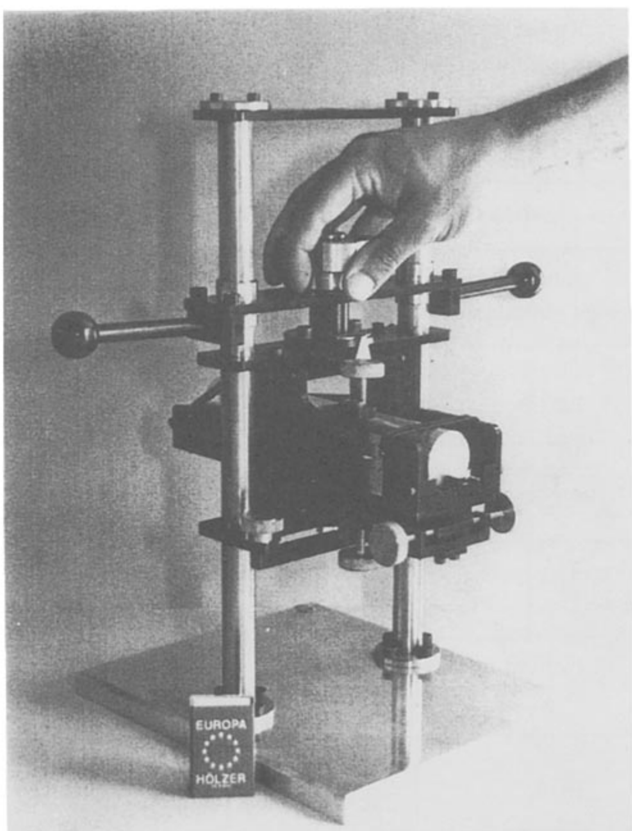

Fig. 5. A device, which was designed and manufactured by a student team.

7. Evaluation

Due to different conditions the two processes 'first day without supervision (A)' and 'methodological development during 10 days under supervision (B)' are difficult to compare. Not only did they have a different time limit (1 and 10 days respectively), they also produced different results (layout and detailed design respectively).

Considering the sub-aim preliminary layout, which occurs in both processes A and B, it would be too easy a judgement simply to state 'Process B is more successful', even though all students and supervisors would agree.

Analysing the project in detail, we identify a number of factors which can also influence the difference in results. These are:

- the different time-frame allowed for the processes A and B.
- The supervision of the systematic design process.
- The learning of design methodology during the process.
- The experience that the students gain in process A and then put into practice in process B.

These factors will briefly be discussed in the following.

If, in considering the high time-intensity in process B (5 days until the preliminary layout), we also take into account the introduction to and the training in design methodology (approximately 40% of the time allowed) there remains nonetheless a considerable time difference. It would be useful to analyse processes A and B under a schedule of equal amounts of usable time and to examine further the time for learning.

The analysis of the videos and interviews do, however, suggest that a longer time period for process A would have had little influence on the approach to concept and layout creation. There would possibly have been more time for additional corrections. However, these would, in our opinion, have been limited to details and therefore not have brought a fundamental improvement of the design.

In terms of effect on the process there is an overlap between that of supervision and that of the usage of design methodology. The external supervisor does, of course, make decisions for the team and thus reduces the number of possible problems. However, whether any type of supervision—without using a design methodological approach—renders positive results, remains to be seen.

The learning of design methodology also has a strong influence on the work of the whole team. The students' mental capacity is not fully devoted to the solution of the design problem but also to the comprehension and application of design methodology.

In this context there emerges the interesting question: which differences would be found if we compared teams with different levels of experience in design methodology?

The experience which the students gain in process A certainly has positive effects on the second process B. A comparison between teams who completed only process A or B would enable us to make a more detailed statement in this context.

The interviews and observations of this study exemplify that structuring the process along the steps of design methodology can improve the success of the design process in the team. Frictions and difficulties in group processes (see Section 5.1) can be avoided by working along defined steps of design methodology. Agreement on systematic steps allowed all team members —despite their different characters and abilities—to cooperate successfully on a common objective.

These results do not claim to make universally valid generalisations about teamwork in design. This first approach is merely meant to describe phenomena and produce hypotheses which can serve as a basis for further systematic analysis in the framework of a research project in the future.

8. Suggestions

The process and evaluation described above renders some suggestions for design research and design education.

Systematic approaches can help to structure teamwork and thus render it more effective. Further projects should research the social, psychological and pedagogical aspects of teamwork in design [14–16].

The methodological approach seems to be most helpful for structuring teamwork during clarifying the task, conceptual design and embodiment design. During detailed design, divisional tasks with control sessions in the group are more useful [17]. Design methods should be examined and classified according to their suitability for teamwork or individual work.

Against the background of this project the following suggestions for further research should be made: The two different processes (teamwork with and without methodical supervision) should be examined and compared within the same time frame to produce the same result.

In future experiments similar to the one described here, the following parameters should at least be considered or systematically varied:

- Kind of supervision (according to methodological approach or to other methods).
- Level of experience in design methodology of the team members.
- Size of the team.
- Relations within the group (e.g., hierarchy or friendship).
- Age difference of the team members.
- Social experience of the team members.

Figure 6 gives an overview of the parameters and

Parameters	Values			
kind of supervision	neutral supervision	supervision according to design methodology	supervision according to other methods	
experience in design methodology	no experience	....	full education in design methodology	
size of the team	3 members	4 members	5 members	....
relations within the group	hierarchy	members have equal standing	friendship	....
age difference of the team members	no big age difference	....	big age difference	
social experience of the team members	no experience in team work	....	experience from expansive project work in teams	

Fig. 6. Influencing parameters and possible values for teamwork.

their possible values. The grey fields illustrate the situation of this project.

Referring to education, the experience of the two different workprocesses A and B, as well as the analysis of the video recordings, was seen as a vital learning process by all students. To work on problems first without and then with supervision—and the comparison between the two approaches by the team members themselves—was an essential element of learning. This technique should be used more often in design education. Video recordings have proved to be very helpful in that context.

The project described in this article required more time and effort of students and supervisors involved than is usually available or required in design education. However, the motivation of the students and the quality of the results in design and production support further such projects in design education. Prospective engineers should be given the possibility to learn the systematic approach in design teams on concrete tasks and thus to prepare themselves for the practical requirements of industry.

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