INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
6 & 7 SEPTEMBER 2012, ARTESIS UNIVERSITY COLLEGE, ANTWERP, BELGIUM

TRANSFER OF ENGINEERING EXPERIENCE BY SHARED MENTAL MODELS

Albert ALBERS, Tarak TURKI and Quentin LOHMEYER
IPEK - Institute of Product Engineering, Karlsruhe Institute of Technology (KIT)

ABSTRACT
The transfer of experience is a great challenge in design education and several approaches support this transfer process. Students gain their own experience in educational project works or they learn from the experiences of their lecturers and tutors. This paper considers the transfer of engineering experience by shared mental model. A mental model is an explanation of someone's thought process about how something works in the real world. In design education the lecturer, who in general is more experienced in analyzing and solving design problems, explains his or her own mental models to the students, in order to share the mental models and thus to transfer experiences. This paper presents a case study that analyses the support of sharing mental models by application of a special type of mechanical design tasks. A case study, which contains a test group of 30 students and a comparison group of 15 students, considers the shared mental models of schematic diagrams as well as shared mental models of designing technical systems. The case study's results finally lead to an explanatory model that illustrates the process of experience transfer by the interdependencies of real world, mental models and design patterns.

Keywords: Experience transfer, mental models, design pattern

1 INTRODUCTION

In engineering design there are several approaches supporting the transfer of experience. In this context most common approaches consider the application of design patterns. A pattern is the description of all invariant features of a multitude of solutions to similar problems in a defined situation [1]. Characteristic for a pattern is a determined structure with regard to contents. Based on experience, an expert (or a group of experts) has to identify and derive potential patterns. For application, a user can retrieve and select an adequate pattern that seems to be promising to solve the identified problem in the given situation.
In design education the application of design patterns appears to be challenging. The selection of adequate patterns, the right understanding of these patterns and the expedient adaption to a present design situation requires a level of experience that most undergraduate students do not possess. The research presented in this paper bases on the assumption that experienced persons like lecturers and tutors, have to share their mental models with the students to allow an effective transfer of experience. The paper describes a case study that analyses the support of sharing mental models by application of a special type of mechanical design tasks. The study contains a test group of 30 students and a comparison group of 15 students. It considers shared mental models of schematic diagrams as well as shared mental models of designing technical systems.
The paper proceeds as follows. Section 2 gives a brief overview of the concepts of mental model and shared mental model. Furthermore the role of shared mental models in education is briefly described. Section 3 points out the importance of schematic diagrams in design. In this context a special type of mechanical design tasks is introduced. Section 4 describes the case study including its research method. In section 5 the case study's results are presented and discussed. They finally lead to an explanatory model that illustrates the process of experience transfer by the interdependencies of real world, mental models and design patterns. Section 6 concludes.

2 SHARED MENTAL MODELS

2.1 Mental models and shared mental models

In order to understand how experts perform tasks based on their knowledge and experience, researchers in several disciplines use the construct of mental models. A mental model is an explanation of someone's thought process about how something works in the real world. It is a representation of the surrounding world, the relationships between its various parts and a person's intuitive perception about his or her own acts and their consequences. The concept *mental model* was originally postulated by the psychologist Kenneth Craik [2] who proposed that people carry in their minds a small-scale model of how the world works. These models are used to anticipate events, reason and form explanations. Johnson-Laird [3] further developed the idea of a mental model in his research on human reasoning. He analyzed the recursiveness of mental models, which characterizes them as dynamic representations. Thus a mental model is never complete, but it continues to be enlarged and improved.

Mental models allow humans to quickly integrate new information and to make predictions with little mental effort. In consequence they support them to reason, explain and anticipate new situations. In most circumstances humans will construct and employ several mental models simultaneously. Based on a literature review Jones et al. [4] identified that mental models are elicited for the following reasons:

- To explore similarities and differences between stakeholders' understanding of an issue to improve communication between stakeholders
- To integrate different perspectives, including expert and local, to improve overall understanding of a system
- To create a collective representation of a system to improve decision making processes
- To support social learning processes
- To identify and overcome stakeholders' knowledge limitations and misconceptions associated with a given resource
- To develop more socially robust knowledge to support negotiations over unstructured problems in complex, multifunctional systems.

In project work that is performed by a team, the team members organize their knowledge of team tasks, equipment, roles, goals, and abilities in a similar way, they share mental models. Thus, shared mental models are the basis of effective communication and cooperation. In this context Badke-Schaub et al. [5] describe that mental models, which are developed and shared in a certain situation, contain knowledge about the task (procedures and constraints), the process (problem solving and decision making strategies) and the team (knowledge and preferences of team member).

2.2 Shared mental models in education

Barker et al. [6] emphasize that the development of mental models is the underlying 'driving force' that forms the basis for all teaching and learning activities. They further propose that the richness of an individual's mental models usually increases with his or her growing maturity and exposure to new and varied experiences and may, ultimately, lead to expert performance. Thus, mental models are important because they form the underlying basis of tasks which involve non-recurrent skills and problem solving.

The building of mental models plays a key role in education. Students are taught how to effectively apply their knowledge in certain situations. The lecturer, who in general is more experienced in perceiving and acting in similar situations, explains the own mental models to the students, in order to share the mental models and thus to transfer the experience once gained. The process of experience transfer can be supported by external representation [7]. Especially in design education the application of sketches and drawings is essential to (partly) externalize mental models. Meinel and Leifer [8] illustrate that in design thinking especially conceptual prototypes have to be understood as communication media that make ideas more tangible. The synthesis of these virtual or physical representations is helpful to establish shared mental model and thus to transfer experience.

The degree of sharedness can be evaluated by practicing tasks or exams that place the student in a comparable, but unfamiliar situation. Reflection and repetition of those tasks support the (temporal) fixation of these mental models.

3 TRANFER OF EXPERIENCE BY SHARED MENTAL MODELS

3.1 Shared mental models in mechanical design

In the mechanical design course of KaLeP [9] students are taught to design technical systems like gear boxes including all shafts, gear wheels, bearings, sealings, joints, clutches and housings. In order to communicate a design task to the students, a combination of specifying description and schematic diagrams are used. These schematic diagrams are simple line drawings that are composed of a limited number of defined icons. Figure 1 (left side) shows an example of a schematic diagram. A shaft is represented by a line, a bevel gear by a line with 45° rotated 'wings' (tooth system) and a joint by two triangles. A schematic diagram illustrates the systems function and structure in an abstract, but also easy way. In order to understand a schematic diagram the mechanical engineering students have to know about the meaning of every icon that is used within it, i.e. they have to build a mental model that is shared among all participants. A mechanical design student, who shares this mental model, is able to explain that figure 1 shows a gear box that consists of two shafts, one hollow shaft, three bevel gears as well as appropriate joints; the rotation incoming from the top is turned in an angle of 90° and furthermore equally split to two out-coming counter rotate shafts (+ω/- ω) on the right side.

Within their project work the students have to design technical systems without a before defined gearbox. Thus, they have to identify the required functions for themselves. The shared mental model of the schematic diagram allows the students to easily communicate their views and ideas within the team. It further helps in negotiation and in specification of a team's final solution.

3.2 Transfer of experience in mechanical design

This section introduced the educational approach of the "creativity potato". Its purpose is to train the design of different gear boxes and to support the transfer the experience gained in the designing of the technical systems. The educational approach bases on the mental model of the schematic diagrams presented above. Figure 1 (middle) illustrates one of several typical tasks the students are confronted with. Instead of delivering the students a completely defined schematic diagram, only inputs and outputs are specified. All essential elements within the "potato" are removed and the students are asked to design a solution that fulfils the required function (fill in the blank). The basic idea of the approach is comparable to a cloze test. The "creativity potato" requires the ability to understand the context of the task in order to identify matching elements and assemblies.

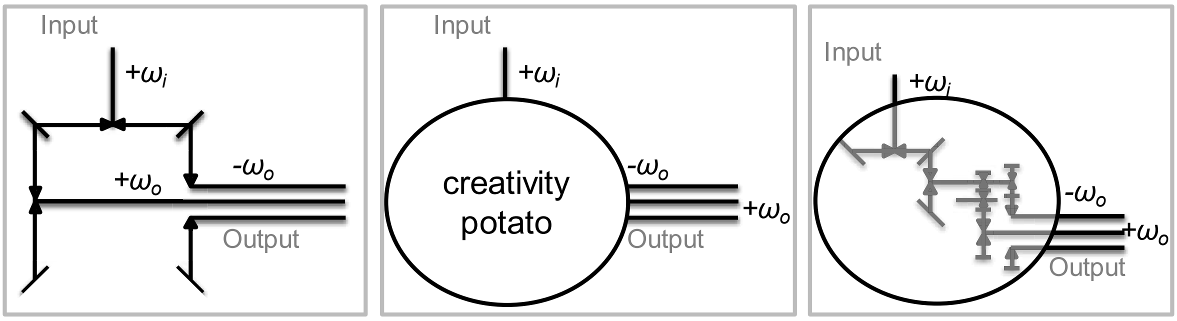

Figure 1. Example of (1) a schematic diagram, (2) a "creativity potato" task and (3) a typical student's solution

While cloze tests are usually applied in language education, the "creativity potato" supports the transfer of design experience: Figure 1 (right side) shows a typical solution presented by a student. This solution fits to the inputs and outputs defined by the task. It further shows the student's ability to work with schematic diagrams correctly. Nevertheless, compared to the solution presented on the left side, there are several differences recognizable (the left solution is much easier and cheaper than the right one). This is explainable by the low level of experience of the student in designing gear boxes. The student's mental models consider design aspects like "a gear wheel is connected to only one other gear wheel" and "first solve the problem of 90° turning, then the problem of rotation splitting". A more experienced person possesses a mental model that includes the left solution, i.e. this person is able to explain the left solution and thus, to share his or her mental model with the student. The transfer of experiences further considers the teaching of different "creativity potato tasks". The higher the number of known tasks and solutions, the higher is the level of experience. Due to this the mechanical design students are encouraged to develop new tasks and share them with each other.

4 CASE STUDY

4.1 Research method

The mechanical design course (MD) starts in the first semester with MD I and ends in the fourth semester with MD IV. The course contains three components lectures, tutorials and project work. The latter builds the framework of this study. In MD, groups of five students have to solve a design task within four months. In order to measure the project success regular milestones are defined. Here, project results that are developed by the students are analyzed and discussed. The design tasks employed in this study is not a part of the student's regular project work.

In winter term 2011/2012 the MD III project work included three milestones. 45 bachelor students participated in the study. The students have been subdivided into a test group of 30 students and a comparison group of 15 students. The study with the test group proceeded as follows.

- 1st milestone: the students solved a design task as presented in figure 2. The drawings have been collected. The solutions have not been discussed with the students deliberately.
- 2nd milestone: the students exercised several variants of "creativity potato" tasks. The results were discussed, adjusted and expanded.
- 3rd milestone: the students solved the same task as assigned at 1st milestone.

The study considered the comparison of the schematic diagrams of the test group from the 3rd milestone with those from the 1st milestone. The students of the comparison group have not been asked to solve the design task at 1st milestone, they have not exercised the "creativity potato" at 2nd milestone, but they have been confronted with the design task at 3rd milestone. The schematic diagrams of the test group have been compared to those of the comparison group.

4.2 Mechanical design task

The design task, the 45 students have to solve in the case study, considers the design of an industrial dough mixer. Figure 2 shows the corresponding schematic diagram. The rotation (and torque) generated by a power unit (not represented in figure 2) enters the technical system by an elastomer coupling hub from the right side. The bevel gear wheel 1 mounted on shaft 1 is in mesh with bevel gear wheel 2. This bevel gear wheel should be connected to shaft 2 by a shaft-hub joint in that way that the agitator at the lower end of shaft 2 is adjustable in height by operation of the hand wheel.

The difficulty of this design task lies in the overlap of a rotational (induced by the bevel gear) and a translational motion (induced by the hand wheel) in exactly that area, that is hidden by the "creativity potato". The design of a solution that solves this problem requires a relative high level of experience. Due to this the presented design task is suitable to analyze the transfer of experiences.

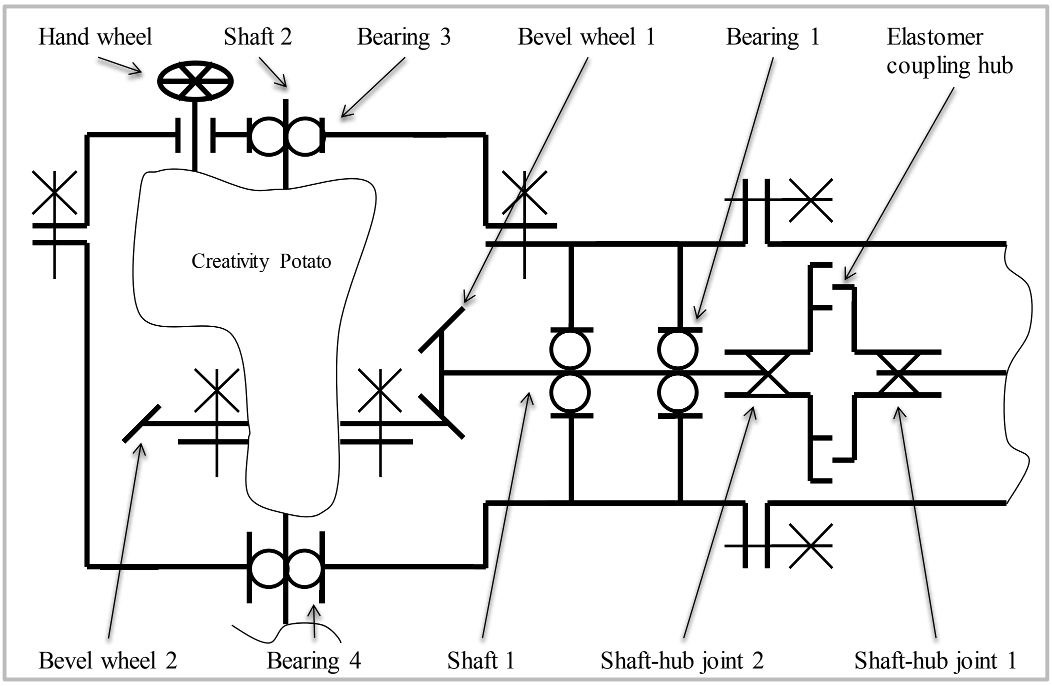

Figure 2.Schematic diagram of the design task including a "creativity potato"

5 RESEARCH RESULTS

5.1 Results of the case study

In the case study 45 students generated a total of 135 drawings of solutions that should meet the assigned design task. Figure 3 shows three demonstrative examples of these drawings that are representative for ca. 70% of the case study results.

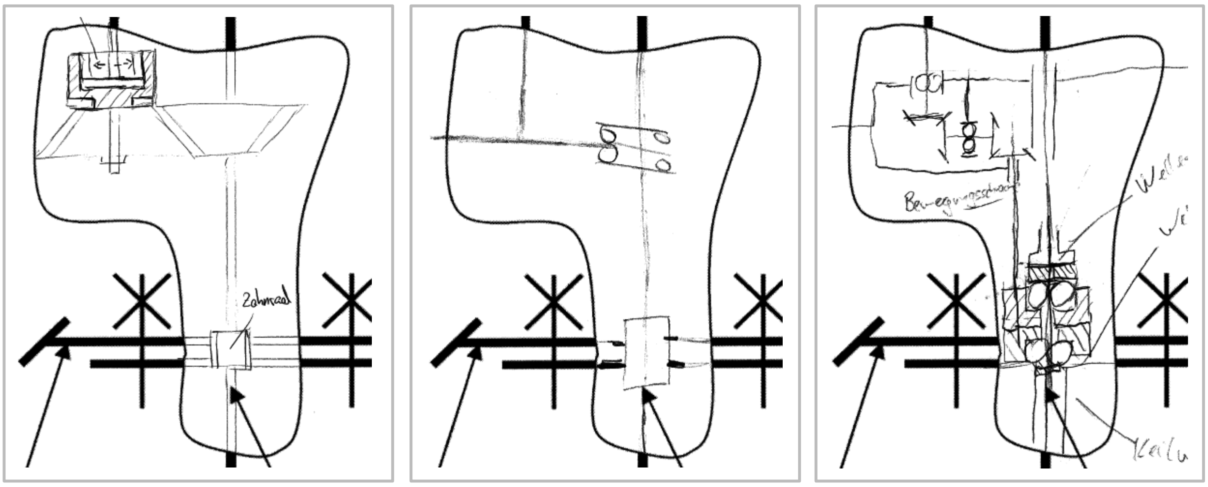

Figure 3. Solutions of task at (1) first milestone of the test group (2) third milestone of the test group and (3) third milestone of the comparison group

The drawing on the left side presents a solution of the test group at the first milestone. It shows that this student was not familiar with the mental model of schematic diagrams. He tried to solve the task by drawing mechanical elements in form of sectional representation. Thus, he needed a lot of time for drawing, which he could have spent to find an adequate solution. The drawing further shows that this student was not experienced enough in designing gear boxes to be able to solve the problem of overlapping rotational and translational motion. The middle of figure 3 presents the solution that the same student generated at the third milestone. It is observable that at this point of time the student shared the mental model of schematic diagrams: the shaft is simply represented by a line; the axial bearings are illustrated by circles and the spline shaft by a box. Although this solution seems to be unspectacular at first sight, it indicates a sufficient high level of experience. This schematic diagram presents a quick and correct solution of the design problem. The drawing on the right side of figure 3 is a result of the comparison group. It shows that the student, who generates this solution, was familiar with the mental model of schematic diagrams, but he was not able to use it consistently. Furthermore this student was not experienced enough to solve the design task.

Based on the presented results it can be assumed that the practicing of different "creativity potato" task at the second milestone has been successful regarding (1) the sharing of the mental model of schematic diagrams and (2) the transfer of experience in mechanical designing of gear boxes.

5.2 Model of experience transfer

Based on the insights that are gained within the presented case study a generalized model of the transfer of engineering experience is proposed. Figure 4 illustrates the interdependencies of real world, mental models and design patterns in the context of experience transfer. Here, design patterns are to be understood as externalized mental models in the form of texts, drawings or physical models.

The processes of experience transfer are represented by two closed loops. The outer loop describes the process of learning by gaining own experiences. Designers as well as design students gain experience in their project work. They build mental models on basis of successful actions and strategies in recurrent situations (cognition). In order to share their mental models with other person, they need to (partly) externalize their mental models in form of design pattern (pattern identification and derivation). These design patterns can be reused to support future real world design activities (pattern application).

The inner loop describes the process of learning from experienced person. A lecturer introduces and explains design pattern to the students (pattern selection). By practicing the application of design pattern in educational tasks (e.g. by application of the "creativity potato") students are able to build shared mental models (pattern internalizing) that allow them to solve real design problems in appropriate situations (recognition).

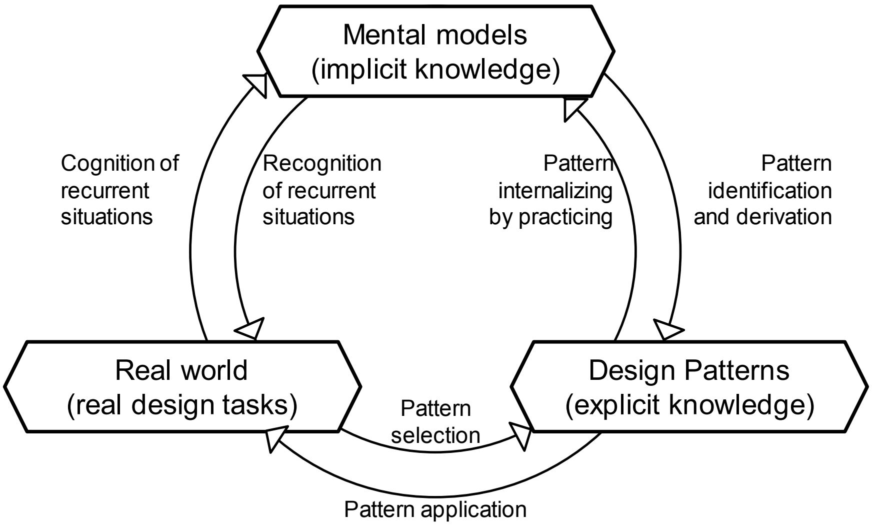

Figure 4. Closed-loop model of experience transfer

6 CONCLUSION

This paper introduced an educational approach for the transfer of engineering experience by shared mental model. The theoretical background of shard mental models has been presented and transferred to the field of mechanical design education. In this context the importance of schematic diagrams in design has been discussed and a special type of the educational tasks, the so called "creativity potato", has been introduced. Within a case study with a test group of 30 students and a comparison group of 15 students on fundamental aspect experience transfer by shared mental models have been analyzed.
The case study's results show that the practicing of different "creativity potato" tasks (2nd milestone) have positive effects on the process of sharing mental model. On the one hand it enables the correct application of schematic diagrams. On the other hand it allows the transfer of mechanical design experiences.
The deduced closed-loop model represents two different ways of experience transfer by sharp mental models. Both ways are relevant in design education: (1) outer loop: students should gain their own experience and share it with others and (2) inner loop: student should learn from the experience of their lecturers and tutors by practicing design pattern and thus share mental models of design.

REFERENCES

[1] Albers A. and Deigendesch T. Patterns in Product Development, 2010. *International Symposium on Tools and Methods of Competitive Engineering TMCE 2010*, Ancona, Italy.
[2] Craik K. J. W. *The Nature of Explanation*, 1943. (Cambridge University Press, Cambridge).
[3] Johnson-Laird P. N. *Mental Models*, 1983. (Cambridge University Press, Cambridge).
[4] Jones N.A., Ross H., Lynam T. Perez P. and Leitch A. Mental Models: An Interdisciplinary Synthesis of Theory and Methods. In *Ecology and Society*, Vol.16, No.1:46, 2011.
[5] Badke-Schaub P., Neumann A., Lauche K. and Mahommed S. Mental Models in Design Teams: A Valid Approach to Performance in Design Collaboration?, 2007. *CoDesign*, Vol. 3(1), pp.5-20.
[6] Barker P., van Schaik P. and Hudson S. Mental Models and Lifelong Learning, 1998. In *Innovations in Education & Training International*, Vol. 35(4), pp.310-318.
[7] Birkhofer H. and Jaensch J. Interaction between Individuals, 2003. In: Lindemann U. (ed.), *Human Behaviour in Design* (Springer, Berlin).
[8] Meinel C. and Leifer L. Design Thinking Research, 2011. In: Plattner H. et al. (eds.) *Design Thinking* (Springer, Berlin).
[9] Albers A. Burkardt N. Deigendesch T. and Meboldt M. Enabling Key Competencies by Educational Project Work Exemplified by Teamwork and Cooperation. *11th International Conference on Engineering and Product Design Education E&PDE 2008,* Barcelona, Spain.