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IMPROVED CODIFICATION AND TRANSFER OF ENGINEERING KNOWLEDGE THROUGH HUMAN INTERMEDIARIES

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Abstract

In multi-domain product development and companies with a high division of expertise, there is a permanent need to transfer expert knowledge to mechanical designers. Especially in large distributed organizations, the “people-to-documents” approach plays an important role since experts are often temporarily or locally not available. However, experts face several problems when they independently codify their knowledge for mechanical designers into a computer-based knowledge system. Difficulties are resulting from the characteristics of expert-layperson communication or from cognitive and motivational barriers. In order to overcome the problems, an intermediary is suggested as a medium to reduce the experts’ effort and support them in anticipating designers’ knowledge needs. For this purpose, an intermediary based knowledge codification method has been applied in a case study in the German automotive supplier industry. Thereafter, the method was evaluated by interviews with experts who have participated in that process.

Keywords: Information management, Communication, Case study

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1 INTRODUCTION

According to Albers et al. (2012) iterations are an essential element of product development to increase the state of knowledge and then to refine the system of objectives. Still, additional iterations to gain knowledge which was already available in the organization should be avoided in order to save development efforts and time. Therefore, companies invest resources in recording and transferring of existing knowledge. The present research in this field is motivated by the experience gained from a case study in a company within the German automotive supplier industry (>100.000 employees worldwide). Due to the large variety of products and customers, a structure of spatially distributed product development and technology research departments has evolved. Especially in the product field of electrical control units, many technologies have to be applied within a very limited design space. In this working area, continuous transfer and application of technology knowledge, methods and tools are essential. The transfer of knowledge via codification and storage in a computer-based information system are necessary elements of the organization's knowledge management. The main three reasons for the computer-based knowledge transfer are the spatial distribution of employees, their temporary unavailability and the vast number of possible knowledge receivers. Technical experts in this organization have been instructed to write down their findings and relevant knowledge in a computer-based information system to make it applicable for mechanical designers. That initial state model is depicted in Figure 1.

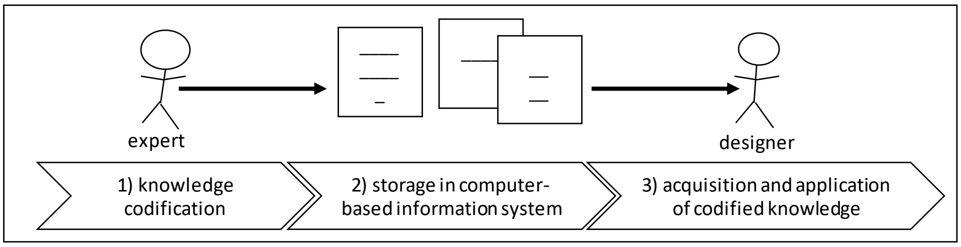

Figure 1. Initial state computer-based knowledge transfer model

Several problems have been observed when experts independently wrote down their knowledge and integrated it into a computer-based knowledge system for designers. For example:

- Documents were difficult to find due to inhomogeneous naming and use of terms.
- Understanding was sometimes difficult due to unclear technical descriptions or graphics.
- Often there was no clear distinction between content which should be applied and content which is just informative.
- The underlying reasons for rules or guidelines were not always explained.

These aspects led to problems of understanding and applying the codified knowledge for designers within product development projects. On the other hand, experts reported a lack of time and resources to create documentations for designers.

2 RESEARCH QUESTIONS AND RESEARCH METHOD

This above described situation motivated this research project to analyse the process of transferring codified knowledge and the participants involved. The questions guiding the research are based on the initial situation that experts solely had to write down their knowledge. Should technology experts or experts from other engineering disciplines independently codify their knowledge in a computer-based information system for mechanical designers? How could an intermediary support that process?
A literature study regarding relevant research fields for the given knowledge transfer setting has been performed. The research fields are covering following areas:

- Expert-layperson communication.
- Cognitive aspects of expertise.
- Motivational factors for knowledge transfer.
- Written instructional explanations.
- Knowledge elicitation techniques.
- Theory of multimedia learning.

In addition, a knowledge transfer method guided by an intermediary has been derived and applied in the above-mentioned company. Finally, semi-structured interviews with experts who participated in the knowledge codification activities have been performed to evaluate the approach from experts' point of view.

2.1 Expert-layperson communication

The process of computer-based knowledge transfer is a way of communication between an expert and a layperson.

In terms of product design, the expert could be a process expert for a joining technology and the layperson is a mechanical designer. The concept of division of expertise allows the designer not to become an expert of the joining technology. But the designer still needs to apply some of the expert's knowledge during product development. On the other hand, designers could have more advanced knowledge about the product and its application and are therefore experts in a different knowledge field. In the expert-layperson setting, the communication theory of common ground by Clark et al. (1991) can be applied. The common ground between two persons is "…mutual knowledge, mutual beliefs, and mutual assumptions." See Figure 2 (left).

In communication, the common ground has to be continuously updated until it is sufficient for the current communication objective. This process is called grounding. Clark states "Once we have formulated a message, we must do more than just send it off. We need to assure ourselves that is has been understood as we intended it to be. (…) our goal is (…) that we and our addressees mutually believe that they have understood what we meant well enough for current purposes."

Both individuals can communicate verbally, nonverbally, by writing or drawing etc. In order to anticipate the layperson's understanding, the expert relies on the layperson's feedback. The clearer the layperson externalizes his understanding, the better the expert can adjust his explanation on his addressee's needs. According to Jucks et al. (2011) "… the main challenge for experts in instructional communication is to build a precise model of the recipient's knowledge base and to adapt their explanations accordingly." In the research of Nückles et al. (2006) online computer support customers had filled out a short self-assessment sheet. Already this information helped experts to communicate more efficiently with their customers. "The assessment tool evidently facilitated the construction of a mental model of the client's knowledge and thereby supported adaptation to the client's communicational needs." In Figure 2 (right) the grounding process by communication is shown.

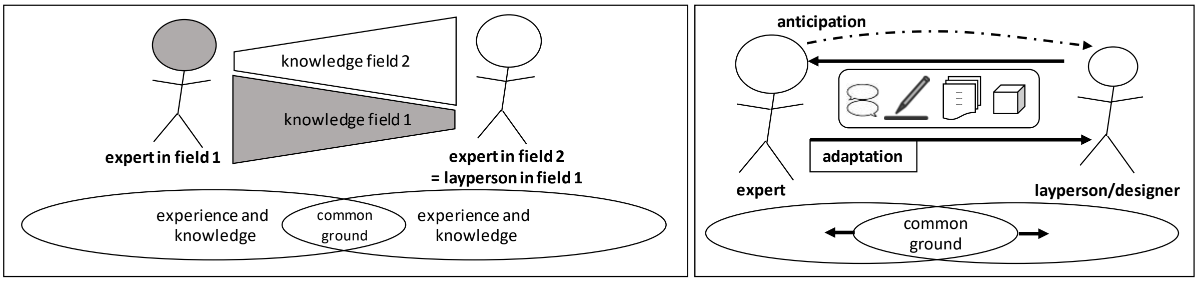

Figure 2. Expert, layperson, and common ground (left), grounding by communication (right)

Reflecting on the situation in the case study, experts would have difficulties anticipating the designers' understanding and knowledge needs. A lack of prompt feedback from designers leads to insufficient adaptation of the codified knowledge from experts within the database. See Figure 3.

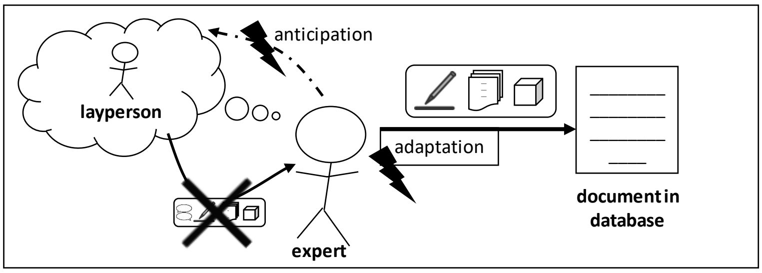

Figure 3. Missing communication when expert independently codifies his knowledge

It could be argued that an expert who has wide range of experience in work with laypersons, e.g. due to project work, has a sufficient understanding of the designers' perspective and would be able to put well-adapted information in the knowledge system. However, this is not the general case and does not sufficiently remove the motivational barriers described in a later section of this paper.

2.2 Cognitive aspects of expertise

Hinds (1999) summarizes three shortcomings of experts estimating the effort novices need for task complementation. A novice in the working field of the expert should in the future develop into an intermediate or even an expert. Although novices have to be distinguished from laypersons, both share a similar asymmetric knowledge setting in relation to the expert. Therefore, the below research findings can be partially applied on the layperson-expert situation of the case study as well.

- **Availability heuristics**
  - Recent and more likely, problem-free experiences of the expert could lead to underestimating task time of novices.
- **Anchoring and adjusting**
  - Experts judge based on their own performance and are not able to assume the gap between their expert skills and the skills of novices.
- **Oversimplification**
  - Due to automation of processes and an oversimplified view, experts are not aware of the task's complexity.

Hinds tested the debiasing methods of asking experts to recall their own experience and the method of giving a list of steps novices need to perform to fulfill the task. The results have shown that the two debiasing methods had a negligible impact on experts' prediction of the time novices need to complete a task. Experts highly underestimated the time novices required. It has been concluded as follows: "Evidence does suggest heavy reliance on an anchoring and adjustment heuristic with experts' own novice performance as the reference point. (…) Evidence from these data suggest that the availability bias is the key contributor to experts' relative inaccuracy in estimating novice performance times." Therefore, the investigation of further debiasing methods is recommended. Intermediaries especially could "(…) assist in predicting novice's performance. I would not suggest eliminating the expert from this process but closing the gap by adding in the perspective of someone closer to the experience of the novices being predicted."
The above-mentioned shortcomings of experts would have also a negative impact on expert's documentations for mechanical designers. As a consequence of overestimated anticipation on task performance, the codified knowledge could be difficult to apply for mechanical designers. Hinds' proposal to overcome experts' shortcomings by introducing a second person who adds the novice's perspective goes in line with the implications of the expert-layperson communication setting.

2.3 Motivational factors for knowledge transfer

According to Cress et al. (2009) knowledge sharing via a computer-based information system can be classified as a social dilemma. In this model, entering information in a database causes immediate costs for the author. Applying information stored by others in the database for one's own purpose is regarded as a benefit. The maximum cost-benefit ratio is achieved when only stored information is used and no information is entered by oneself. However, if the whole group of database users is acting in this way, there will be no usable information in the database. The cost-benefit ratio would be very low. This social dilemma can be referred in this context as an "Information exchange dilemma". See Figure 4.

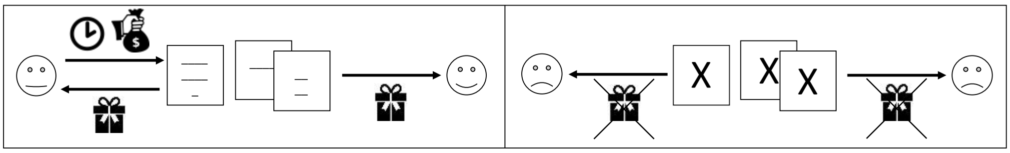

Figure 4. Information exchange dilemma

Costs are affected by an increased time and effort for writing down information, creating pictures, structuring content or embedding documents within the database structure. When this cost is too high motivation of experts declines accordingly. Two other demotivation factors are anonymity and nonpersonal communication when exchanging information in a database. Cress' experiments under laboratory conditions simulated information sharing for salary calculations in a fictive company. The results show inter alia following:

- **Awareness of importance of information**
  - The more one's own knowledge is regarded as relevant for others, the more information will be added to the database.
- **Cost of entering information**
  - If time cost for entering important and less important information in the database are identical, much more important information are shared (ca. 65% vs. 24%). If sharing important information costs double time, much less important information is shared (ca. 30% vs. 42%).
- **Reducing uncertainty through feedback and recommendations**
  - If others' knowledge sharing behaviour is perceived as very active, more information has been shared.
  - A recommendation system to enter more information resulted in participants to do so.

As a consequence, it has been concluded by Cress that to encourage people to share their knowledge, the resulting benefits should be fostered. E.g. granting the opportunity to gain a positive reputation within the organisation. Knowledge sharing costs on the experts' side should be reduced. The other group members' needs should be apparent and a common goal and a high group identity will also be supportive.

A possible way to implement these recommendations is to introduce an intermediary who fosters experts' motivation to share their knowledge with the least cost and effort. By repeatedly emphasizing the importance of the experts' knowledge, the intermediary already could show acknowledgement which then leads to higher motivation of the expert. The cost of entering information for experts can be significantly reduced by shifting this task to the intermediary. A high commitment of an intermediary in the knowledge transfer process could be indirectly motivating experts to engage also more actively. This would reduce the experts' uncertainty of how much they are expected to be participating.

2.4 Written instructional explanations

As stated by Wittwer et al. (2008), written instructions do not have the benefit of face-to-face explanations where the expert can monitor the learner's comprehension and therefore has the chance to clarify the content if necessary. On the other hand, written instructions have other advantages. Learners can repeatedly read, underline, summarize the instructions and elaborate a profound understanding. However, these instructions also need to take the learners prior knowledge into account and have to be adjusted accordingly. Computer-mediated instructions from experts to a large group of anonymous knowledge receivers with varying knowledge base is a very difficult task. For example, when a person with a high level of knowledge base has to read very detailed instructions, the person has to read a lot of contents which have already been understood. This redundant contents will claim cognitive resources and can degrade the learning performance. This correlation is called expertise reversal effect. See Figure 6, left.

The expertise reversal effect can be taken into account by different approaches within knowledge representation in a computer database. For example:

- **Structure of the document** (e.g. single file reports)
  - Interconnection to other relevant documents content can be difficult.
- **Hypertext** (e.g. Wiki)
  - Too many links and possible reading paths may overexert readers.
- **User adaptive database**
  - Creation of the database system is complex and new content is probably more difficult to add.

See Figure 5, right.

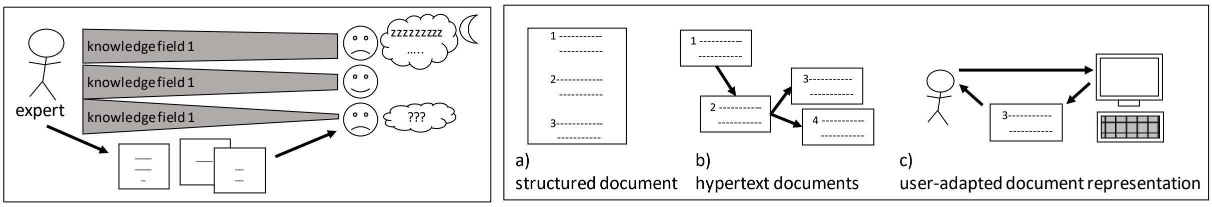

Figure 5. Challenges of different prior knowledge (left), ways to overcome these (right)

Besides taking the knowledge receivers' perspective into account, experts also need to arrange their documentation in a way which considers readers' different prior knowledge. This requires additional skills of experts and furthermore causes additional workload during the documentation process. A way to relieve experts is to let these tasks be performed by an intermediary who is trained for that. This would allow the organisation to introduce more sophisticated documentations forms like hypertexts or even content in user adapting documentation platforms.

2.5 Knowledge elicitation techniques

2.5.1 Knowledge based engineering "KBE"

Verhagen et al. (2012) describe “The objective of KBE is to reduce time and cost of product development, which is primarily achieved through automation of repetitive design tasks while capturing, retaining and re-using design knowledge.” In order to convert expert knowledge into an automated software tool “[…] the role of the knowledge engineer was created. “ Emberey et al. (2007) The knowledge engineer, also called analyst, elicits the expert’s knowledge using different elicitation techniques and consecutively develops software which can be applied by designers. Among many available techniques, Jafari et al. (2011) refers interviewing as the one used most often.

Verhagen also points out when not to use KBE. In a design process where technology is constantly changing or creative processes are involved, KBE is not practicable. Also, high effort is necessary to develop and maintain automated software. Economies of scale can only be achieved when the software can be applied very often. Among other points, Verhagen criticizes “case-based, ad hoc development of KBE applications” and “a tendency toward development of ‘black-box’ applications” where the designer doesn’t know what the software is actually doing.

But from a wider point of view and not taking expert software as the single target product of KBE, other knowledge transfer cases can profit from KBE research results. Schiuma et al. (2012) state that after the research fields of knowledge management and knowledge engineering have mainly developed in parallel, now both research fields could mutually benefit from one another. In knowledge engineering, the elicitation of the expert's knowledge has been regarded as the bottleneck in the knowledge transfer process. Therefore, extensive research has been performed on the processes of elicitation, structuring and representation of knowledge by an analyst. Surprisingly, in knowledge management, the role of an analyst does not exist. This might be due the assumption that experts proactively share their knowledge. However, due to lack of motivation, opportunity or ability, experts do not share their knowledge proactively. In order to overcome procrastination or avoidance of knowledge sharing, it is recommended to introduce the role of the analyst in knowledge management. The special trained analyst has the organisation's mandate to spend time and effort on knowledge elicitation, structuring and representing experts' knowledge.

If the analyst is solely a specialist in knowledge transfer related activities, there is a risk that the knowledge receiving group's perspective and needs are not sufficiently considered. Therefore, a person belonging to the group of knowledge receivers is recommended to take over the additional role of a so-called analyst.

2.5.2 Collaborative development of knowledge representations

The approach developed by Garcia-Perez et al. (2009), Garcia-Perez (2010) focuses on the transfer of knowledge between key experts and stakeholders. After the objective of a specific knowledge transfer project has been set, the newly introduced role of a knowledge transfer facilitator starts with a document analysis and one-to-one interviews with all involved individuals. The aim is to get an understanding of the topic and the individuals’ perspectives and their knowledge needs. During the next phase, the knowledge facilitator organizes and moderates meetings involving both groups in which the knowledge

representations are collaboratively developed. Between the meetings, the facilitator's work is to prepare the results from the last meeting and distribute the results to the participants. In the following meetings, the modeled representations are reviewed and further developed. The knowledge transfer between experts and stakeholders takes place during the meetings and the development of the models. The "[…] method aims at facilitating interaction between participants and, as a side effect, relevant knowledge can be captured." (Garcia-Perez et al., 2009). Except for the knowledge facilitator, no significant amount of work besides the meetings is required by the individual participants. This iterative approach was successfully applied in several industrial case studies and it has been evaluated that this method motivates experts to contribute their knowledge and increased their ability of doing so.
The method requires several meetings with experts and several stakeholders who come together at the same time. It is not determined how to represent the results for third parties. However, it shows that several iterations of meetings support to develop a common understanding and enlarge the knowledge of the target group. Especially the preparation and follow-up processing of the meetings by the so-called knowledge transfer facilitator highly contributes to the success of this method.

2.6 Theory of multimedia learning

The efficient application of codified knowledge is influenced highly by the way it is presented. Due to poor instructional design, an unnecessarily high cognitive load is put on the reader. According to Mayer (2014), one target of a good instructional design is to reduce extraneous processing so the reader can focus on the complexity of the content and does not loose motivation. Another target is to ease or manage essential processing which is the processing of the material within the working memory. Important content from non-imported content is filtered and a mental model is created. Furthermore, generative processing should be fostered. This aims on making sense of the represented material. Confirmed by multiple experimental studies various instructional design techniques are proposed by Mayer. For example:

- **Minimize extraneous processing**
  - Coherence principle: Eliminate extraneous material.
  - Signaling principle: Highlight essential material.
  - Spatial contiguity principle: Place printed text near corresponding graphic.
- **Manage essential processing**
  - Segmenting principle: Break presentations into parts.
  - Pre-training principle: Describe names and characteristics of key elements in advance.
  - Multimedia principle: Use text and pictures rather than text alone.
- **Foster generative processing**
  - Personalization principle: Use conversational text style.
  - Guided discovery principle: Provide hints and feedback as learners solve problems.

Applying the guidelines of the theory of multimedia design in engineering education by Garner et al. (2013) or medical education by Issa et al. (2013) has shown significant effects on improving learners' understanding and recalling ability and reduced the amount of misconceptions.
To introduce these principles of multimedia learning into the codification process of expert knowledge, each expert would need to be trained accordingly. This would have a negative impact on the experts' motivation due to the additional knowledge sharing cost. It would also be not efficient to train all experts if they only occasionally create documents for mechanical designers. It is more efficient that fewer persons acquire these skills and are granted to apply these techniques more regularly.

2.7 Interim conclusion

Influencing factors on the transfer of knowledge via codification have been investigated from diverse research fields. A repetitive suggestion is to introduce a role of a person who is supporting the knowledge transfer process. Several names have been found to be linked to that role, e.g. knowledge agent, knowledge engineer, knowledge transfer facilitator, knowledge transfer intermediary or analyst. Following the term knowledge transfer intermediary, in short, intermediary is used. The derived tasks of the intermediary for the context of the before mentioned case study are listed on Figure 6.

Characteristics and tasks of the knowledge transfer intermediary:

- Intermediary belongs to the group of intended knowledge receivers.
- Represent the knowledge receivers' group perspective.
- Give feedback about the experts explanations (verbal, text, graphics).
- Help the expert to overcome cognitive shortcomings.
- Motivate the expert to share knowledge by reducing the experts' workload, highlighting the importance of the expert's knowledge and reducing uncertainty by giving feedback and recommendations.
- Applying knowledge elicitation techniques with experts.
- Iteratively develop the content with the expert, prepare meetings and do follow up processing.
- Structuring and linking the codified knowledge within the computer database.
- Considering differing prior knowledge within the group of knowledge receivers.
- Apply techniques of multimedia learning to make the codified content efficiently applicable.

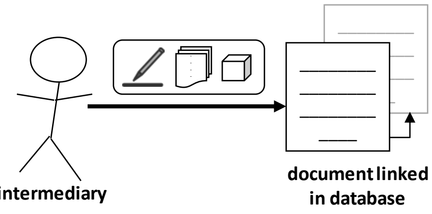

Figure 6. Intermediary's task based on previous literature discussion

The initial computer-based knowledge transfer model (See Figure 1) can be extended by the role of the knowledge transfer intermediary as show in Figure 7.

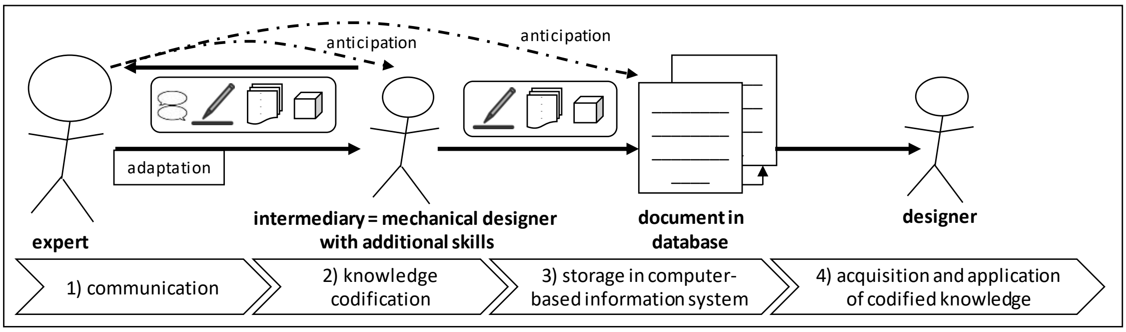

Figure 7. With intermediary extended computer-based knowledge transfer model

3 APPLICATION OF AN INTERMEDIARY IN PRACTICE

3.1 Introduction of the intermediated knowledge transfer

Within the above-mentioned company, a role of the knowledge transfer has been introduced and refined in ten knowledge transfer projects. The method applied is described in Figure 8.

1) Intermediary Start-Up
Intermediary receives already existing documents from the expert. (e.g. presentations, reports) Intermediary reads the documents to get an understanding of the specific knowledge field. Arising questions are collected.

2) Kick-Off Workshop
Intermediary organizes a meeting with the expert. The expert explains what knowledge from expert's perspective should be transferred. The intermediary tries to clarify the questions which came up during step 1).

3) Iteration Phase A – Knowledge Codification
Intermediary starts a codified description of the knowledge field according to the structure of the computer-based knowledge system and requirements of knowledge representation for designers including text, sketches, pictures etc.
Open questions are continuously collected. Intermediary organizes meetings with the expert in order to check the intermediary's description and to work on the open questions. Additionally, new knowledge content which should to be transferred can be identified. This is repeated until the codified knowledge is satisfactory for both the expert and the intermediary.

4) Iteration Phase B – Designer Feedback and Improvement
The intermediary organizes a meeting with other designers and it is checked if the codified knowledge is applicable. Further questions are noted and later on, clarified with the expert. This is repeated until the designers are satisfied with the codified knowledge.

5) Release
When expert, designers and intermediary agree to the applicability of the codified knowledge, it is released in the computer-based knowledge system.

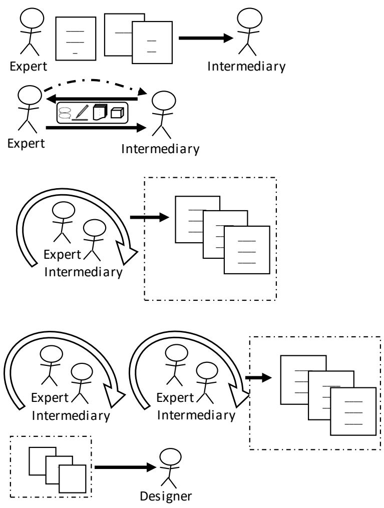

Figure 8. Knowledge elicitation and codification method with an intermediary

As a documentation platform, a wiki has been used and for the structuring of the content, a pattern language has been developed. The pattern language structure was set up in a way that it addresses the different experience and knowledge levels of designers. Missing design rationale in the descriptions can be omitted since the pattern structure requires a problem description before a solution is given.

3.2 Evaluation of the intermediated knowledge transfer method

Semi-structured interviews with 7 experts who have been involved in the knowledge transfer process were performed. The interview duration has been between 20 to 40 minutes. The interviews' audio was recorded, transcribed, anonymised, paraphrased and finally clustered to find experts' main statements about the experts' self-assessment, the newly introduced method and the requirements on the knowledge transfer intermediary. If a contrary statement has been done, it would have been listed as well.

- **Experts' self-assessment:**
  - A high knowledge level on designers' side is assumed. A documentation solely written by experts would have not focused that much on basic principles. Rather big effort would have been put into discussion of technical details. (5x mentioned)
  - Beside project related work, there is hardly any time to do such a documentation solely by the expert. (5x mentioned)
  - The effort to create a documentation solely by the expert is perceived as very high. (4x mentioned)
  - Documentations made during research projects by experts are assumed to be hardly usable for mechanical designers. (4x mentioned)
  - Experts would be willing to learn how to use a wiki platform. (3x mentioned)
  - Learning the usage of a wiki by experts would be not efficient since it will be used very rarely as an author. (2x mentioned)
  - Experts see a risk for themselves when designers wrongly apply the experts' documentation. (3x mentioned)
- **Experts' feedback regarding the newly introduced method**
  - There is no risk when somebody else documents the experts' knowledge when there is a review process. (6x mentioned)
  - Experts were motivated by the chance to share their knowledge within the organization. (4x mentioned)
  - Experts were motivated by the possibility to have less workload in the future. (4x mentioned)
  - The workload for the experts was very low. (4x mentioned)
  - The ratio of workload and benefit is positive. (4x mentioned)
  - The perspective of the non-expert improves the documentation. (3x mentioned)
  - The questions of the intermediary helped to clarify misleading descriptions. (4x mentioned)
  - Experts receive a feedback about how good their explanations are. (3x mentioned)
  - Pictures created by the intermediary are very detailed and helpful. (3x mentioned)
  - A consistent structure for all documentation topics is important and useful. (4x mentioned)
  - There were no additional technical findings for the experts. (4x mentioned)
- **Requirements on the knowledge transfer intermediary:**
  - Basic technical understanding. (6x mentioned)
  - Ability to structure many and complex topics in a simple way. (3x mentioned)
  - Strong communication skills. (3x mentioned)
  - Persistence and patience. (3x mentioned)
  - Structured working style. (2x mentioned)
  - Organization skills (1x mentioned)
  - Self-confidence to repeatedly ask when something is not understood. (1x mentioned)
  - Organization of all activities during the knowledge transfer process should be done by the intermediary. (1x mentioned)

4 CONCLUSION

Experts' self-assessment is in line with the findings from literature. The perceived risk for experts' who share their knowledge for mechanical designers via documentations should be reduced. It should be clearly stated during the documentation process and within the documentation database, that the content is to the best of expert' knowledge and belief and that the expert is not liable for any misuse of the documentation. The documentation method with an intermediary was well accepted. The advantages of the role of an intermediary have been confirmed from the viewpoint of the experts. Finally, some requirements of the intermediary from experts' side have been identified. This can help to identify potential employees who could work as a knowledge transfer intermediary. However, this is only the point of view from the experts' side. Additional research regarding the skills and requirements on the intermediary from the organizations and the knowledge receivers' perspective needs to be performed. In summary, the role of the intermediary in computer-based knowledge transfer is highly recommended.

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