Empirical Validation of Knowledge Packages as Facilitators for Knowledge Transfer

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Abstract. Transfer of research results in production systems requires, among others, that knowledge be explicit and understandable by stakeholders. Such transfer is demanding, as so many researchers have been studying alternative ways to classic approaches such as books and papers that favour knowledge acquisition on behalf of users. In this context, we propose the concept of Knowledge Experience Package (KEP) with a specific structure as an alternative. The KEP contains both the conceptual model(s) of the research results which make up the innovation, including all the necessary documentation ranging from papers or book chapters; and the experience collected in acquiring it in business processes, appropriately structured. The structure allows the identification of the knowledge chunk(s) that the developer, who is acquiring the knowledge, needs in order to simplify the acquisition process. The experience is needed to point out the scenarios that the user will most likely face and therefore refer to. Both structure and experience are important factors for the innovation transferability and efficacy. Furthermore, we have carried out an experiment which compared the efficacy of this instrument with the classic ones, along with the comprehensibility of the information enclosed in a KEP rather than in a set of Papers. The experiment has pointed out that knowledge packages are more effective than traditional ones for knowledge transfer.

Keywords: Knowledge package; knowledge base; open innovation.

1. Introduction

The ever greater pressure of competition to which firms are subjected has made product and process innovation a crucial issue. To increase the production and the delivery of technological innovation, the dynamic integration of many competences and different knowledge produced and provided by different organisations is necessary. Successful innovators must complement in-house knowledge with technologies from external sources (Chesbrough et al., 2006). Consequently, R&D is shifting from its traditional inward focus to more outward-looking management that draws on knowledge from networks comprised of universities, start-ups, suppliers and even competitors (Chesbrough, 2003).

The above considerations are particularly valid within Software Engineering (SE). Indeed, knowledge is a critical production factor because software development (production and maintenance) is human centred and because software process products are meant to be used in order to enforce capabilities in each application domain. As such the knowledge needed is both of a technical and social nature. The first type includes knowledge of methods, techniques and processes for building and maintaining software products, in other words: knowledge of the technologies that apply to software development. The second type includes knowledge on the behaviour of the developer and stakeholder needs. Knowledge involves two types of problems:

— **Transferability and consequent reusability.** Much of the knowledge used in development processes is tacit, and much is hidden in processes and in products (Foray, 2006). Indeed, it is known that tacit knowledge concepts emerge consequently to events that are not necessarily planned. Knowledge hidden in processes and products is not even readable by its authors in that it is spread out and confused in many of the process or product components (Foray, 2006; Laudon and Laudon, 2008). So, until knowledge is transferable or reusable, it cannot be considered as part of an organisation’s assets (Foray, 2006).

— **Knowledge exploitation.** Research produces knowledge that should be transferred to production processes as innovation in order to be valuable. This need is pointed
out by the continuous trend of open innovation (OI). In other words, the phenomena of exchanging research or innovation results among research groups or enterprises (Chesbrough et al., 2006). The logic of OI characterises the end of the XX century and forecasts that enterprises develop their projects in collaboration with other sites. In contrast to the principles that had characterised Closed Innovation, the divulging idea is that of: internal R&Ds holding part of a knowledge that comes from external R&D; creation of a business model that assumes a primary role in the knowledge development lifecycle; sharing knowledge with other enterprises in order to achieve higher quality levels (Chesbrough et al., 2006). OI supports solution of these issues through exchange of research results: the enterprises or institutions export research results that are not yet accessible and usable; enterprises that are able to exploit the results in the short term can import them from the organisations that make them available. The logic behind OI emphasises knowledge transfer, from research to production processes, i.e. how research results are to be applied. Consequently, domain knowledge must be enriched by technical and economical knowledge that allows to identify the best approach for introducing new knowledge in processes together with the resources, risks and mitigation actions (Reifer, 2003).

The first problem requires formalising knowledge so that it is comprehensible and reusable by others who are not the author of the knowledge. The second problem requires experience packaging able to guide the user in applying the knowledge in a context. Given these premises, this paper describes an approach for Knowledge Experience Packaging (KEP) and Representation and reports the preliminary results of a first experimentation of the KEP without needing support from the knowledge authors.

In this work, we named ‘traditional approach’ the approach based on the use of papers, book or, in general, nonstructured text for knowledge transfer and acquisition.

The rest of the paper is organised as follows: related works are described in Sec. 2; Sec. 3 illustrates the proposed approach for knowledge representations; in Sec. 4, an empirical investigation is described; Sec. 5 illustrates the used measurement model; results of the study including statistical analysis and lessons learned are presented in Sec. 6; finally conclusions are drawn (Sec. 7).

2. Related Works

The problems related to knowledge transfer and valorisations are investigated in industrial and academic contests and sometimes it is not possible to distinguish the two contexts because there is a convergence between industry and academia. Some companies have established internal organisations whose task is to acquire new knowledge (Hastbacka, 2004; Halvorsen, 2004; Philips Research Password Magazine, 2004) to face knowledge transfer needs. For example, Shell Chemical has organised some groups with the scope to finding knowledge from outside sources (Hastbacka, 2004), Hewlett Packard is commercialising not only its own ideas, but also innovations from other entities (Halvorsen, 2004), Philips Research is participating in consortiums that direct one-to-one collaborations with innovative organisations (Philips Research Password Magazine, 2004).

There are also many studies that are focused on the use of Internet together with its Search Engines for knowledge diffusion and transfer (Demirci et al., 2007; Tumer et al., 2009; Spink et al., 2006; Leighton, 1996; Chu and Rosenthal, 1996; Clarke and Willett, 1997). These studies confirm that also in the more recent investigations the available Search Engines have more limitations and low performances. In this direction, our analysis shows that the Internet does not offer appropriate technologies for searching knowledge that is produced and published by a
research organisation nor by an enterprise, which is reusable in innovation projects by other research organisations or enterprises. A validation of this statement is proposed in Ardimento et al. (2008). The most accredited reason for this limitation is that usually general queries produce a large amount of documents and that there is no natural language interface for the search engine. The latter technology improves the search precision although it does not overcome the problems described above.

There are also many approaches based on the use of specialised search engines in the way to find search results related to a specific application domain (Kitchenham, 2007).

Another approach to knowledge search and transfer is based on the use of ontology (Zhang et al., 2004; Mingxia et al., 2005). This approach is actually the object of many studies which currently lack tools for creation and management. Much attention is being focused on these issues but the available experimental evidence is not yet sufficient for large-scale use.

In this work, we proposed an alternative approach to knowledge transfer based on concepts of knowledge packaging and knowledge base. The problem of knowledge packaging for better use is being studied by many research centres and companies. The current knowledge bases in literature sometimes have a semantically limited scope. This is the case of the IESE base (Althoff et al., 2001) that collects lessons learned or mathematical prediction models or results of controlled experiments. In other cases, the scope is wider but the knowledge is too general and therefore not very usable. This applies to the MIT knowledge base (Malone et al., 2003), that describes business processes but only at one or two levels of abstraction. There are probably other knowledge bases that cover wider fields with greater operational detail, but we do not know much about them because they are private knowledge bases; for example, the Daimler-Benz Base (Schneider and Schwinn, 2001; Daimler-Benz Knowledge Base, 2009). There is another recent KEB, known as DAU (DoD Acquisition Best Practices Clearinghouse, 2009) which is not structured as our KEB but has many key performance indicators similar to ours. As such, we are designing a survey, in collaboration with the authors of the DAU KEB, among stakeholders to verify which of the two bases is more acceptable. If they are comparable, we will evaluate them in terms of efficacy and comprehensibility.

3. Proposed Approach

Our approach focuses on a knowledge base, named Prometheus (http://prometheus.serandpractices.com), whose contents make it easier to achieve knowledge transfer among research centres; between research centres and production processes; and among production processes. The knowledge base must be public to allow one or more interested communities to develop around it and exchange knowledge (Ardimento et al., 2006). The knowledge that is stored in the knowledge base must be formalised as a KEP. A KEP is any cluster of knowledge, sufficiently familiar that it can be remembered rather than derived.

3.1. Knowledge package structure

The proposed KEP structure includes all the elements shown in Fig. 1. More details are provided in Cimitile (2008) and Visaggio:
A user can access one of the package components and then navigate along all the components of the same package according to her/his training or needs. Search inside the package starting from any of its components is facilitated by the component’s attributes. For all the components, these allow rapid selection of the relative elements in the knowledge base (Ardimento et al., 2006; Cimitile, 2008).

The Knowledge Content component (KC or Knowledge) is the central one. It can be seen in Fig. 2 that KC contains the KEP expressed in text form and may also contain figures, graphs, formulas, and whatever else may help to understand the content. The content is structured as a tree. Starting from the root (level 0), navigation to other levels (level 1, level 2…) occurs through links. The higher the level of a node, the lower the abstraction of the content, which focuses more and more on operative elements. The root and each intermediate node contain the reasoned index of the underlying components. The content consists of the following: research results for references, analysis of how far the results, used for the innovation, can be integrated into the system; analysis of the methods and details on how to transfer them into the business processes which collect all the experience and the changes occurred in time during projects (each project is an experience of the application of the innovation to a specific scenario); details on the indicators listed in the attributes of the KC inherent to the specific package, analysing and generalising the experimental data evinced from the evidence and associated projects; analysis of the results of any application of the package in one or more projects, demonstrating the success of the application or any improvements required, made or in progress.

When knowledge of some concepts is a prerequisite for understanding the content of a node, the package points to an educational e-learning course (Ardimento et al., 2006). But, if use of a demonstrational prototype is required to become operative, the same package will point to a training e-learning course (TE), as shown in Fig. 1 (Ardimento et al., 2006).

When a package also has support tools, rather than merely demonstration prototypes, KC links the user to the available tool. For the sake of clarity, we point out that this is the case when the KEP has become an industrial practice, so that the demonstration prototypes included in the archetype they derived from have become industrial tools. The tools are collected in the Tools component (TO). Each available tool is associated to a corresponding TE course which teaches how to use each tool.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Contents</th>
<th>eLearning</th>
<th>Relations</th>
<th>Attachments</th>
<th>Knowledge Supplier</th>
<th>HELP SUPPLY</th>
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Including a BSC in a GQM

An approach that has had large success within SPI in industrial contexts is the Balance Scorecard framework. Within the community of computer scientists, the Goal Question Metrics (GQM) Paradigm has also been developed. The possibility of including BSC concepts in GQM would give users the advantage of having a single quality system as support to operational and strategic issues of an enterprise.

The issue of unifying the two quality approaches is motivated by the economics of management and design of quality models and of their corresponding measurement plans. Also, use of a GQM that includes BSC makes the entire quality system more readable, and therefore easier to verify and validate. Moreover, a greater readability of the quality system and its verification and validation implies that all the interested stakeholders understand and share the quality system itself. For completeness, the concepts of Verification and Validation are detailed in GQM-ComSo.

This package summarised the Balance Scorecard and the Goal Question Metrics (GQM) Paradigm, and the Method for Including a BSC in a GQM. Finally it is introduced the Relation between GQM and BSC. The method is validate by designing a GQM from a BSC - Evidence. This evidence consists in applying the proposed method to two industrial BSCs. The evidences allow to obtain some general considerations on the comparison between BSC and GQM. Also, they prove that the author's conjectures on the method and on the value for stakeholders are valid hypothesis. Therefore they are worth an experimental validation on behalf of interested researchers.

Fig. 2. Example of a content of a knowledge package.
A KEP is generally based on conjectures, hypotheses and principles. As they mature, their contents must all become principle-based. The transformation of a statement from conjecture through hypothesis to principle must be based on experimentation showing evidence of validity. The experimentation, details of its execution and relative results, are collected in the Evidence component (EV), duly pointed to by the KEP.

Finally, a mature KEP is used in one or more projects, by one or more firms. At this stage, the details describing the project and all the measurements made during its execution that express the efficacy of use of the package are collected in the Projects component (PR) associated with the package.

4. Controlled Experiment

4.1. Research goals

The approach aims to verify the approach of knowledge representation through KEP collected in the Prometheus tool, compared with equivalent knowledge expressed in papers and in sources extracted from the web and used for the production of a knowledge package. In particular, in accordance with the research questions, it investigates quality characteristics of efficacy and comprehensibility.

For efficacy we investigate whether the analysis and extraction of knowledge through a KEP requires less effort than through papers; for comprehensibility we investigate whether knowledge extraction is less prone to error if KEPs are used rather than papers. Indeed, in the latter case, knowledge is most likely scattered in various parts of the paper or papers. With respect to this characteristic, we also investigate whether given a topic (from here on indicated as problem) it is more difficult to understand the problem and extract knowledge from papers rather than a KEP.

The following Research Goals have been defined:

\textbf{RG1}

Analyse knowledge extraction using KEP
With the aim of evaluating it
With respect to efficacy (compared to knowledge extracted from papers)
From the view point of the knowledge user
In the context of a controlled experiment on a knowledge package tool called Prometheus

\textbf{RG2}

Analyse knowledge extraction using KEP
With the aim of evaluating it
With respect to comprehensibility (compared to knowledge extracted from papers)
From the view point of the knowledge user
In the context of a controlled experiment on a knowledge package tool called Prometheus

In accordance with the above goal, the following research hypotheses have been made:

\textbf{Efficacy:}

\(H_0^{EFF} : \) There are no statistically significant differences in terms of effort for solving problems assigned using KEP rather than papers.

\(H_1^{EFF} : \) There are statistically significant differences in terms of effort for solving problems assigned using KEP rather than papers.

\textbf{Comprehensibility:}

\(H_0^{COMPR} : \) There are no statistically significant differences in terms of the degree of correctness of answers using KEP rather than papers.

\(H_1^{COMPR} : \) There are statistically significant differences in terms of the degree of correctness of answers using KEP rather than papers.

4.2. Experiment description

4.2.1. Experiment variables

The dependent variables of the study are Efficacy and Comprehensibility. Efficacy of the KEP is measured in terms of effort spent for extracting knowledge and answering a specific set of questions. Comprehensibility is measured according to a score assigned to the content of each answer. The same variables are measured for the resources described in Prometheus and in Papers.

The independent variables are the two treatments: the problems examined with KEP and with Papers in literature. Two different types of problems were investigated: Balanced Scorecard and Reengineering Process.

For each problem, a set of four questions have been defined. This has been considered an appropriate number that balances the need for a sufficient amount of data without having to count on an excessive amount of effort and risk to bore and tire experimental subjects. Each question has a different complexity level (H or L). Two questions have a H complexity level and other two are rated as L for both treatments: KEP and Papers. For clearness, the question is classified as complexity L if its answer can be localised in a part of the document, not larger than a page; rather it is considered H if the answer to the question refers to information sparse in multiple parts of the document that cover an area which is greater than a page. Since the structure of KEP and Paper are different: the same question may have different complexity level, depending on the knowledge representation method.
used, because the locating the answer may depend on how the content is organised in PROMETHEUS rather than in PAPERS.

4.2.2. Selection of experimental subjects

The experimental subjects involved in the experimentation are first-year students of a graduate course in Informatics.

A total of 82 students have been divided into two groups (Group A and Group B) by random assignment to each one. Each group was asked to answer questions assigned using KEP or Papers extracted from literature.

All of the students have previous knowledge of the topic concerning Balanced Scorecard because it is part of their course curricula, while they have previous knowledge of the Reengineering Process topic.

4.2.3. Experiment design

The design is represented in Table 1.

The experiment was organised in two experimental runs, RUN1 and RUN2, one per day in two consecutive days. Each run applied the design above. During each run, we changed the content of the KEP vs Papers and the content of the questions used to extract information from the source. Moreover, in RUN1, the KEP vs Papers content, along with the questions for extracting information, related to Balanced Scorecard (Becker and Bostelman, 1999; Grembergen, 2000; Abran and Buglione, 2000; Mair, 2002) and in RUN2 they referred to Reengineering (Bianchi et al., 2000, 2001, 2003).

Within a RUN, each group was assigned to either one of Factor A and to all the levels of Factor B. The assignments were inverted for the successive run. A summary of the assignments is reported in Table 2.

As it can be seen, within the same run the subjects use the same topic and the questions are the same.

For each Run, the experimental subjects had at the most 1 h:30'. The time was limited to that to avoid subjects getting tired and bored, which could have influenced their performances and represented a possible threat to the experiment.

4.2.4. Instrumentation

During each experimental run, for each analysed problem, experimental subjects were provided the following instrumentation:

— a general description of the problem;
— the KEP or set of Papers concerning the problem. The package is accessible through Prometheus. The papers are provided in digital version;
— a set of questions related to the problem;
— data form: in which each experimental subject must report their name, last name, start and end time, and answers to the questions.

4.2.5. Operation

At the beginning of each run, each experimental subject received a complete set of instrumentation (described above). It contained the Papers or KEP according to the treatment and group. The students examined the material and answered the questions, reporting them on the data form. The start and end time were recorded by the researchers when handing in and collecting the forms.

<table>
<thead>
<tr>
<th>Table 1. Experiment design.</th>
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<tbody>
<tr>
<td>FACTOR B: knowledge extraction problems</td>
</tr>
<tr>
<td>LEVEL1</td>
</tr>
<tr>
<td>(Q1)</td>
</tr>
<tr>
<td>FACTOR A: Knowledge representation</td>
</tr>
<tr>
<td>LEVEL 1: Knowledge package</td>
</tr>
<tr>
<td>KEP/Q1</td>
</tr>
<tr>
<td>LEVEL 2: Paper</td>
</tr>
<tr>
<td>Paper/Q1</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Table 2. Summary of assignments for each experimental run.</th>
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</thead>
<tbody>
<tr>
<td>RUN 1</td>
</tr>
<tr>
<td>GROUP A</td>
</tr>
<tr>
<td>GROUP B</td>
</tr>
</tbody>
</table>
Comprehensibility was evaluated according to the number of errors made, while the effort is reported on the data form.

5. Measurement Model

Given the above research goals and the research hypotheses, the dependent factors and the measures used to calculate such factors have been defined according to the GQM quality model (Basili et al., 1994).

The introduced metrics are collected as Prometheus and Paper metrics. The metrics described in Tables 3 and 4 have been collected on both types of knowledge extraction treatments. The introduced metrics according to the Efficacy Factor are given in Table 3.

Another factor is Comprehensibility. It is measured as the average scores $S_{ij}$ attributed for answering the $i$th question of the $j$th experimental subject. All answers were evaluated according to the interval scale reported in Table 4.

For clarity, a wrong answer in this case would generate a threat of improper application of the innovation. This could mean that investments made lead to different and incorrect results. A missing answer does not lead to such a threat and outlines the need to improve the contents of the KEP. As such, the first case is rated with a lower score than the second. The scale in Table 4 is clear for the other two cases.

Note that the researchers, as domain experts involved in the investigation, corrected all the answers to the questions given by the experimental subjects.

6. Experimental Results

The data collected during the experimentation have been synthesised through descriptive statistics. This allows to represent them graphically, identify possible outliers and decide if they must be eliminated from the sample. Finally, data has been analysed through hypothesis testing and validated with respect to a significance level of $\alpha = 5\%$.

In the next sections, the results have been commented for both dependent variables: effort (used for measuring efficacy of the knowledge representation technique) and comprehensibility of the technique adopted.

6.1. Efficacy

As pointed out in the experimental design section, in case of effort, the design is reduced to a 1 factor 2 levels design, in that it has been considered as overall time for answering all four questions.

In RUN1, the subject performances, as shown in Fig. 3 are closer. The mean values are, respectively, 0.0643 for PROMETHEUS and 0.0657 for PAPERS. Also, the dispersion of the results is very high for both knowledge representation methods. It seems as if the performances are independent from the technique used. Our explanation is that the experimental subjects were familiar with the topic (Balanced Scorecard) and so they used their previous experience and knowledge to answer the questions rather than strictly relate on the technique assigned (KEP or Papers).

Following to descriptive statistics, a parametric $t$-test was carried out. As expected, the differences between levels of treatments were not statistically significant (Table 5). This confirms that experimental subjects scarcely used the techniques and relied on their previous experience and knowledge to answer the questions rather than strictly relate on the technique assigned (KEP or Papers).

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Figure 4 illustrates the average effort in hours spent by each experimental subject in RUN2. It can be seen that there is less dispersion in the results for both knowledge representation techniques. Also, it can be seen how subjects using Papers spent, on average, a larger amount of time for answering the questions. This suggests that the structure of the packages promotes a more appropriate search of the knowledge contents for answering a question.
Table 5. Hypothesis testing for effort in RUN1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>PROMETHEUS Mean</th>
<th>PROMETHEUS Std.Dev.</th>
<th>PAPERS Mean</th>
<th>PAPERS Std.Dev.</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effort in hours-RUN1</td>
<td>0.643229</td>
<td>0.152905</td>
<td>0.657903</td>
<td>0.120458</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3. Effort in prometheus and papers during RUN1.

Fig. 4. Effort in prometheus and papers during RUN2.
Hypothesis testing, for this factor, was carried out with a $t$-test, on the sample size of 82 observations. The $p$-level in Table 6, assures that the difference between effort is significant and this confirms that KEP is more effective than Papers.

### 6.2. Comprehensibility

Given the experimental design, a $2 \times 4$ analysis of variance with a between-factor (Knowledge Representation: PRO-METHEUS vs PAPERS) of two levels, and a within-factor (PROBLEMS: Q1, Q2, Q3, and Q4) of four levels was carried out for investigating comprehensibility, i.e. an ANOVA repeated measures analysis was carried out.

In RUN1, Fig. 5 shows the trend of comprehensibility with respect to the questions, which appears to be analogous in both representation methods. This confirms our assumption that subjects have most likely used their previous knowledge on the topic to answer the questions within RUN1. This hypothesis is confirmed by observing that the trend of efficacy is not correlated with the complexity of the questions (in order of index, for PROMETHEUS the complexities are H,H,L,L; and for PAPERS they are H,L,H,L). In each case, comprehensibility with Prometheus is always better than with Papers.

The differences between comprehensibility values are all significant, as it arises from the $p$-levels reported in Table 7. It refers to the differences between treatments with respect to each question $Q_i$ ($i = 1, \ldots, 4$).

As descriptive statistic, Fig. 6 shows the interaction effect between the factors Problems*Knowledge Representation with respect to comprehensibility in RUN2.

![Fig. 5. Comprehensibility in prometheus and papers for problem during RUN1.](image-url)
The graph points out that overall comprehensibility is better when Prometheus is used.

This result is confirmed by the univariate test of significance carried out to investigate the differences in means for each problem, between the two methods used.

Table 8 points out that differences are statistically significant. The test points out those differences in correspondence to treatments in each question are statistically significant. So, the observations made in the descriptive analysis are confirmed.

In this run, the complexity of the questions are correlated with the efficacy (in order of index, for PROMETHEUS the complexities are L,L,H,H; for PAPERS they are: L,H,L,H).

7. Conclusions and Future Works

The experiment described in this paper has produced a first empirical evidence on knowledge description through an instrument which has implemented our proposed
approach, called PROMETHEUS. The evidence collected has provided a first attempt to confirm the validity of the structure of a KEP in the tool.

Moreover, we can summarise that the structure of the KEP:

— requires less effort for extracting information searched;
— represents explicit knowledge in a more comprehensible form with respect to traditional descriptions used to formalise knowledge, like papers and books.

The university context is generally considered of scarce interest for empirical investigations, as students do not have the same maturity of professional developers. In this specific case student subjects are considered to be appropriate in that knowledge transfer is more critical when previous knowledge of users is low. To this end, note that the experiment has pointed out the efficacy of the KEP technique when the subjects lacked of previous knowledge on the topic.

These first empirical results induce us authors to continue our validation, with particular attention to industrial contexts. As so, in order to generalise the validity of the KEP proposed in this work many replications and further studies extended to other contexts are needed. For this reason, the authors intend replicating the experiment, and to promote the collaboration of other researchers and practitioners towards empirical validation of KEPs, making instruments and material available to other interested researchers.

For sake of completeness, it is the case to say that we are aware that the structure of our KEP requires more effort for producing KEP with respect to competitor KEB. It is therefore important to prove that the higher effort needed is repaid by a higher efficacy. This investigation will be possible once we have collected a sufficient number of KEP.

**References**


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